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The Magazine of Scientific Progress

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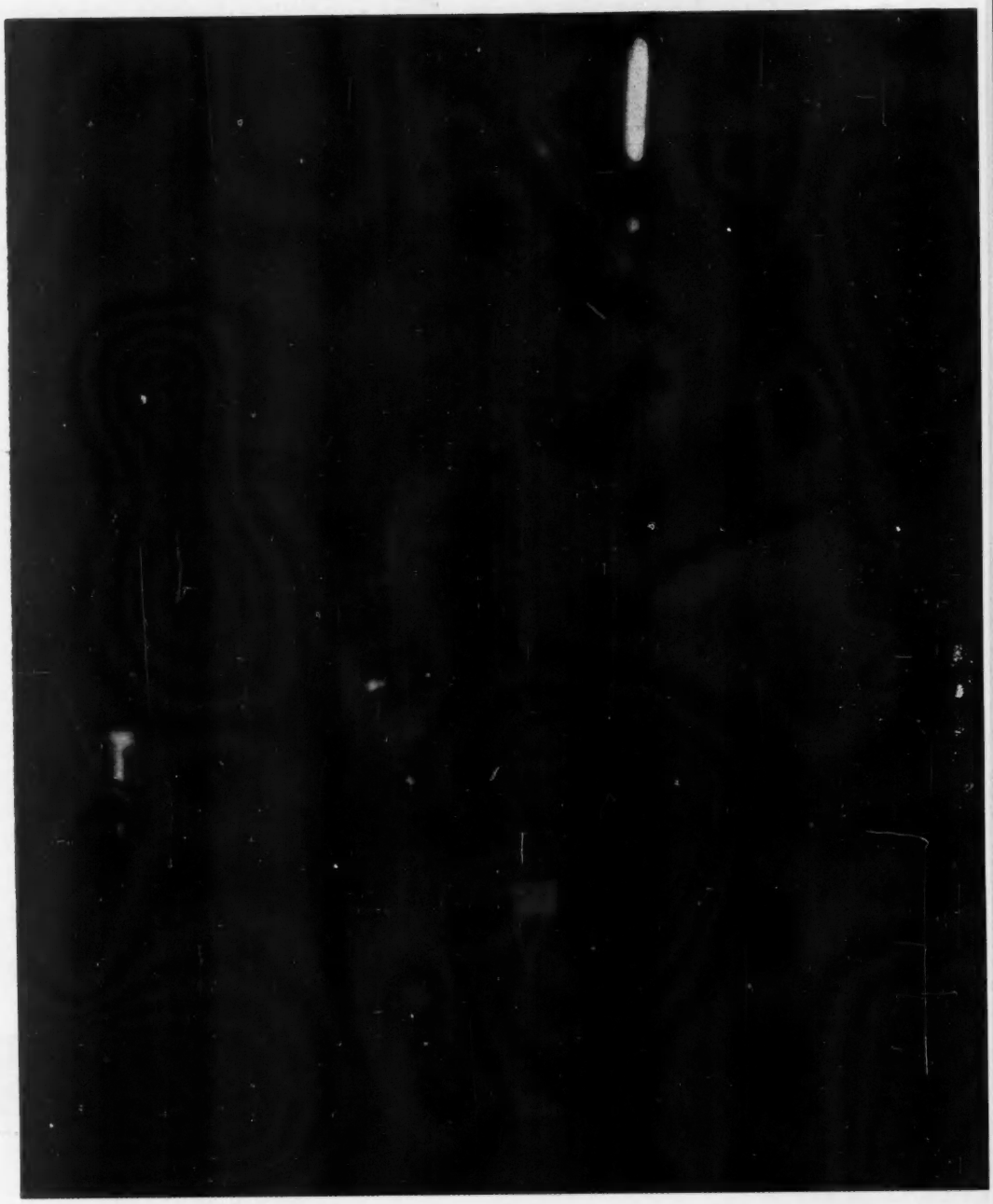

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OUR COVER PICTURE

Seen through a six-foot water window, radiation from the man-made element curium causes materials round it to glow red. The blue colour is Cerenkov radiation. This experiment, run during the summer by Dr. Sherman Fried and colleagues in a reactor at Idaho, succeeded in separating 30 micrograms of californium which will be used in an attempt by Albert Ghiorso to make element 104.

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THE PROGRESS OF SCIENCE

World films at Rabat

The fifteenth Congress of the International Scientific Film Association was held in Rabat from September 16th to 27th. This was the first I.S.F.A. gathering in Africa, and the response from that continent was disappointingly small. Inevitably the technically advanced countries must have a far greater interest in the research film, and while the popularisation of science is an urgent requirement for underdeveloped countries, the role of film for this purpose in Africa must at present be a limited one.

There were fewer films this year—165 from 21 countries as against well over 200 at most previous congresses—and there seemed to be far fewer outstanding contributions, although the general level was good. The only British film to receive an award was A.E.I.'s recently released "Electron Microscopy—an introduction", directed by Michael Crosfield. Great Britain had one of the largest entries of 15 films (which included notable award winners elsewhere) such as Skinner and Thompson's "The Alder woodwasp and its insect enemies", Unilever's "Outline of Detergency" and British Oxygen's "O is for Oxygen".

In the Popular Science Section, Eastern Europe and the U.S.S.R. had an almost clean sweep with seven of the nine awards, including a beautiful example of the historical science film in the East German "Robert Koch" and the Bulgarian "A world in a waterdrop". This latter film confirmed one's impression from the previous two congresses of the high standard of Bulgarian production, achieved by beautiful photography, careful editing and a very well-defined subject presentation.

Any system of awards must invite criticism, simply because it is so difficult to established objective standards of comparison. In the Popular Science Section, for example, were a number of Indian entries on such subjects as "Uranium", "Fight the flood", "White manure" (sulphate of ammonia as a fertiliser) and "Bhakra Nangal" (construction of the world's highest dam). Put alongside the Diploma winners and others of interesting film entry they come out badly as film. But when they are considered as low budget productions designed to meet the government requirements of one public information film per public cinema performance they can be seen as films undertaking a major task of popularising scientific and technical development. Yet a system of awards based primarily on film quality must always reject such films.

Is not here to be found some of the weakness of this I.S.F.A. Congress and a warning for future development? Encouragement of the development of scientific film making must be directly related to serious discussion of the use of such films. Yet this conference in particular was notable for the very limited discussion either on problems of film making or use, and some of the papers circulated to delegates were at a very elementary level. This suggests that far more attention should be given to problems other than film screening. After 15 years I.S.F.A. has hardly begun to appreciate the problems of presenting science to the public on films.

Nuclear tests and the arms race

The alarming prospect of a rapid and increasing rise in fallout is of course not the only after-effect of the resumption of nuclear testing. Among other things, it is certain to lead to a radical acceleration of the arms race to improve the whole range of offensive and defensive missile systems.

A good deal of the pressure on both the Russians and Americans to resume testing has come from the new and as yet untested generation of high yield/low weight nuclear warheads; if the tests on these are successful they will allow both sides either to increase greatly the destructive power of existing missiles or considerably extend their ranges (by decreasing payloads). Since 1958, when the U.S. carried out its only complete test of a missile with a

THE DRAMATIC PROOF OF EINSTEIN'S THEORY CAME WHEN, EARLY IN 1961, SCIENTISTS IN GENEVA FOUND SOMETHING THEY COULD SEND ON A ROUND TRIP AT ¾ THE SPEED OF LIGHT, OR ABOUT 500,000,000 M.P.H. THIS WAS THE "MESON" AN ATOMIC PARTICLE THAT IS KNOWN TO HAVE A "LIFETIME" OF A MILLIONTH OF A SECOND.
BUT IT WAS FOUND THAT WHEN ACCELERATED TO ¾ THE SPEED OF LIGHT THE MESON LIVED 1½ TIMES AS LONG AS NORMAL!
PRECISELY WHAT EINSTEIN PREDICTED!
2-5
WHILE MAN TRAVELS IN THE EARTH'S OWN SOLAR SYSTEM, THE SPEEDS REACHED WILL NOT BE GREAT ENOUGH FOR THIS EFFECT TO BE NOTICED. BUT ONCE JOURNEYS THROUGH THE UNIVERSE TO OTHER STAR SYSTEMS BECOME POSSIBLE, RETURNING TRAVELLERS WILL FIND THAT THEY WILL HAVE TRAVELLED FORWARD IN TIME.... OUR TIME....WHILE RETAINING THEIR OWN YOUTH!
SUN
4½ LIGHT YEARS 20,000,000,000,000 MILES
ALPHA CENTAURUS
IT IS POSSIBLE THAT A YOUNG BOY, LIVING TODAY, COULD GO ON A FLIGHT INTO SPACE AND RETURN TO EARTH TWO HUNDRED YEARS FROM NOW AND STILL BE A YOUNG MAN!

The "Daily Herald" has broken new ground in scientific journalism by using a picture-strip technique to explain the discoveries and concepts of science to its readers. Called the "Frontiers of Science" the strip is under the direction of a prominent Australian physicist, Professor S. Butler of the University of Sydney, and in its second week probed the intricacies of relativity and time dilation with 5 strips, 16 pictures and 21 captions.

nuclear warhead aboard—twice with the *Redstone*—many new missiles have been developed, including *Atlas* and *Polaris*, *Titan* and *Minuteman*. With underground tests, the Americans should now be able to perfect the designs of nuclear warheads specially constructed for these weapons.

By exploding in the atmosphere, the Russians will have the advantage of being able to test their newly developed missiles with warheads fitted ; it will also be possible for them to test the ability of hardened missile sites to withstand nuclear attack. However, if these tests allow them to perfect the 40 to 100 megaton "Doomsday" warhead, most of the American defence system—based on the concept of the fixed, hardened missile site—will be rendered almost entirely obsolete. As a result, there may be a strong swing over to the land-based version of the *Polaris* submarine—highly mobile, ICBM weapons mounted on road or rail trucks. American tests of high yield/low weight warheads should help the changeover. It would be interesting to know, incidentally, how the American Navy reacted to the Russian warning that their test series would include "live" missile shots into the Barents and Kara seas. The American Polaris submarine fleet is known to be operating in this area.

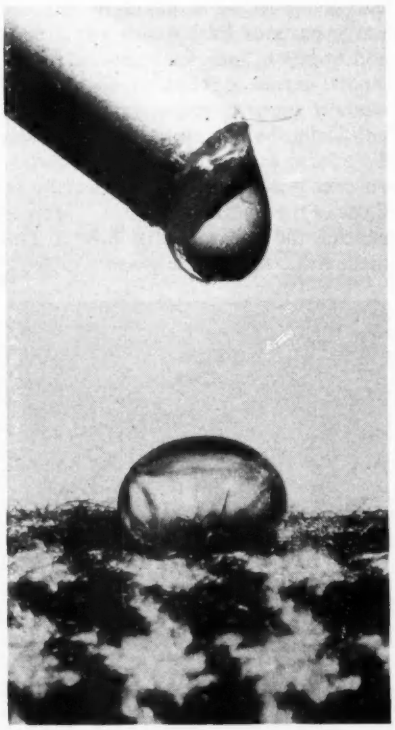
Turning to the conventional armoury, the Admiralty decided last month that in future all ships of more than 6,000 tons will be nuclear-powered. A practically simultaneous report from the United States General Electric Company announces that the possibility of automation for nuclear-powered vessels is both feasible and economically attractive. They have estimated that a nuclear-powered 44,000-ton tanker could be run for 20 years by automatic control with a reduction in cost of between $500,000 and $750,000.

Roman and pre-Roman excavations

Two of the most interesting excavations that have been carried out during the summer months have been in Cambridge and Winchester.

At a site in Gloucester Terrace, Cambridge, Dr J. Alexander has been conducting an extra-mural training dig, looking for the stratified remains of the Roman occupation of Cambridge. Beneath the Roman layers he found two circular V-shaped ditches—one of 40 foot and the other of 90 foot diameter—that probably marked the outline of huts or enclosures. In the ditches were a large quantity of Belgic (Iron Age C) pottery, animal bones and well-preserved crania of cows and goats. The pottery can be dated to about the late first century B.C. Three distinct layers of occupation were identified. The significance of these finds is that they constitute the first unambiguous evidence of a pre-Roman settlement at Cambridge.

In Winchester, Martin Biddle has been in charge of an excavation in a race against time and building contractors. From the Roman site that has been investigated a mosaic, 6 foot wide and with a plaited rope pattern surrounded by a red brick border, has been dicovered. It seems to have run alongside a 30-foot courtyard of a large Roman house, and probably dates from the 3rd century. At another Roman site several roads of varying dates have been discovered, some superimposed on each other. Altogether more than 500 finds have been made, excluding pottery fragments, and about 250 Roman copper coins dating from the 3rd and 4th centuries have been uncovered.



A globule of water on a proofed fabric—a still from the Unilever film "Outline of Detergency" shown at the I.S.F.A. Congress.

New life for the life sciences

During September two outstanding events suggested that the human and life sciences are at last demanding the attention they deserve. At the London meeting of the International Council of Scientific Unions the proposal for an International Biological Programme (comparable in scale to the IGY) was approved and planning begun. Returning from the important Arusha conference on African wildlife, a group of leading biologists, with Prince Bernhard of the Netherlands as their patron, launched an international appeal to help save the world's wildlife. The British appeal is headed by H.R.H. the Duke of Edinburgh.

The decision to go ahead with the IBP programme is immensely encouraging. Roughly speaking, its aim is to co-ordinate worldwide research into the biological condition of the earth as a whole, and of the human race in particular. According to the author of the scheme Dr G. Montalenti, professor of genetics at Rome, one of the first objectives will be to study how the progress and demands of civilisation are changing the relation of man to his environment : he cited the mounting pressure of population, atmospheric pollution (by smoke and radioactivity), and the breaking up of isolated communities as three examples of increasing rapid change in which the human race might be the first to suffer. The aim of the IBP will be not so much to prevent these changes, but simply to describe them and predict what might happen.

It is the next stage in the growth of the IBP which will be crucial—the appointment of a committee to outline a specific work programme. This may well take some years, and may run into difficulties since the commitments for both men and money will be in the hands of scientific institutions of the ICSU member countries. So it still remains to be seen how high a priority the world is prepared to grant to a

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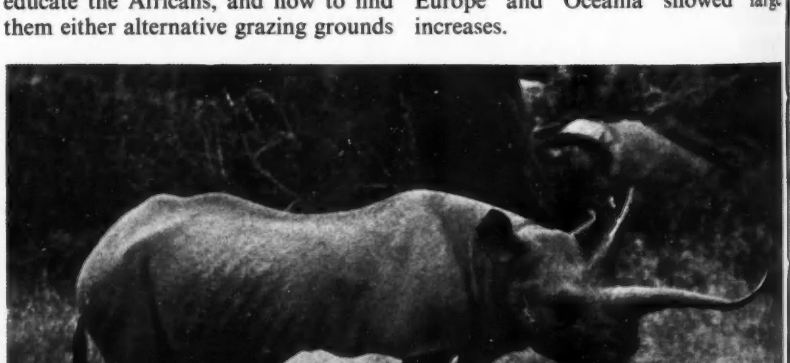
concerted effort of this kind. (In passing, it is interesting to note that while the Berlin crisis was raging, the ICSU Assembly accepted the East German Academy of Sciences for membership within a matter of days.)

Anything which may relieve the dangerous state of emergency now facing the world's wildlife must be seized upon. For this reason the World Wildlife Fund launched in London last month is encouraging, though the question of what good it will do remains open. With an annual expenditure of £500,000, the organisers claim, "most of the seriously threatened species and their natural haunts could be saved. Twice that sum could start constructive conservation of wildlife on a world scale". This may be true : certainly, if the money is not raised then the handful of people now engaged in conservation will lose their (and our) battle and many species of wildlife will vanish within a few decades.

But, as the recent Arusha conference has shown, it looks as if the problems of conservation—especially in Africa—are going to be appallingly difficult. Large parts of East Africa are already a dust-bowl, and if something fundamental is not done soon to hold the country together physically as well as politically the devastation will increase. To a large extent the blame can be laid on over-grazing by cattle, especially by those of the wandering Masai. How to educate the Africans, and how to find them either alternative grazing grounds or an alternative way of life, will be one of the first problems.

Yet the Arusha conference did come up with several useful suggestions. Most important, it laid down several firm propositions which should become the commandments of future conservation work. The first is that while rescue operations on dying species are important, it is far more urgent to preserve natural habitats. Secondly, even wild lands need careful tending—the habitat is not something that we can leave to nature. The third proposition is that given an adequate habitat even a wild population of plants or animals can produce surpluses for human food without any risk of damage to the population ; often, especially in the game lands of East Africa, it is far more profitable to crop meat food from wild animals than from domestic species.

That this last point about food sources is still critical was emphasised in October by the publication of the FAO's annual report for 1961. While the world population rose by 1.6% in the last year, food production was up by only 1% (excluding China). If China is included the total figures of food production would probably show a decline on the previous year. The discouraging figures are largely due to poor harvests in Latin America, Eastern Europe and the U.S.S.R. ; the Far East (apart from China), Western Europe and Oceania showed large increases.



Because its horns are thought to possess magical properties when ground up and eaten, the rhinoceros joins the list of animal species threatened with extinction.

SCIENTIFIC CO-OPERATION AND DISARMAMENT

PROFESSOR ALEXANDER HADDOW, F.R.S.

The Seventh and Eighth (Pugwash) Conferences on Science and World Affairs were held at Stowe, Vermont, in September, on the subjects of "International Co-operation in Science" and "Disarmament and World Security." A word of explanation is indicated as to the change of title of the Pugwash Movement. Very many supporters, especially in the United States, had believed the movement too important to be attached to any particular place or person: hence the new (and very suitable) description—Conferences on Science and World Affairs (COSWA).

After a very agreeable and encouraging message of welcome from President Kennedy, the meetings were opened by the Governor of Vermont, with speeches also by Dr. Detley Bronk on behalf of the National Academy of Sciences, and by Dr. Hudson Hoagland as President of the American Academy of Arts and Sciences, with acknowledgments to the Ford Foundation, which supported the meetings financially. It is useless to ignore that the proceedings took place under the cloud of the Soviet resumption of nuclear test explosions in the atmosphere. A message from Mr. Khrushchev, referring with regret to this change of policy, was communicated to the Conferences a few days later by Academician Topchiev and protests directed to the Soviet government were subsequently lodged by Linus Pauling, and by Professor Toyoda of Tokyo.

International co-operation

The first Conference was attended by some 50 participants from 12 countries, including a strong representation from the U.S.S.R. Its work was carried out in various study-groups and by the delivery of papers. Study-groups operated under the following heads: (1) Exchange of persons and information; (2, 3, 4, 5) Co-operation in the earth sciences, space sciences, life sciences and physical sciences; (6) Co-operation in assistance to developing nations. Of special interest were long discussions of the Bronk-Nesmeyanov agreement, affecting scientific exchange between the U.S. National Academy of Sciences and the Academy of Sciences of the U.S.S.R. Although some appeared in favour of its abandonment on account of excessive rigidity, eventually it was hoped that it might be extended and liberalised, on the way towards more independent and flexible arrangements between individuals and Institutes in the East and West, with no necessity for any too inflexible *quid pro quo* in the process of exchange. S. G. Korneev gave a fascinating account of the growth of scientific interchange between the Soviet Union, the U.S.A. and other countries over the past few years; from negligible beginnings, it is still on far too modest a scale. It was pleasant also to learn from our Russian colleagues the extent of their appreciation of arrangements in this field made with the Royal Society in London.

Disarmament

Even more than the first, the ensuing Conference, on Disarmament and World Security, appears to have been affected by the prevailing and unpropitious political climate. But great efforts were made towards constructive approaches, among others not least by the British members, who on this occasion included Professor P. M. S. Blackett, Sir Edward Bullard, Sir John Cockcroft, Mr. Michael Howard, the Rt. Hon. Mr. Noel-Baker, and Sir William Penney. In addition to reaching an agreed communiqué, the Conference also established an East-West study group to examine its conclusions at greater length, which conclusions and accompanying ideas will then be submitted to the governments of the participating scientists, and to the United Nations.

The writer believes this last point to be of cardinal importance. It is obvious that the main function of these Conferences must be the promotion of international scientific co-operation and understanding, with the hope and intention to induce some betterment in world affairs. After decades of study and discussion on the subject, modern scientific responsibility seems abundantly clear. If this is true, then responsibility must lead to action and effect if we are not to fail. And here we recall the hasty efforts to organise international intellectual co-operation under the auspices of the League of Nations before the last War—efforts which enlisted many high ideals, but which, because of the unreality of their execution, proved in the end a delusion.

Before the Sixth Pugwash Conference, held in Moscow towards the end of 1960, it was apparent that the movement had achieved much good, in establishing better understanding within the international scientific community, and in promoting public appreciation of the issues involved. During that meeting many came to feel a sense of fuller optimism that these endeavours would have an even greater impact in the field of policy and affairs. However, such hopes very rapidly became dissipated in the weeks and months which followed, and the movement now faces an unquestionably critical stage. In its immediate evolution, it must be zealous in defending complete independence of thought. And means must be devised of conveying its views to the heads of governments and to the United Nations, directly and as frequently as necessary, not by nationals alone but by small international groups specially selected. It has never been pretended that the movement affords any panacea, and the immense inherent difficulties have never been minimised. Yet it may be that present failure lies in the lack of sufficiently direct, urgent, and independent representation, to all the centres of political decision.

The undoubted difficulties now confronting us, whilst perplexing, are no reason for abandoning the ideal. On the contrary, they call for redoubled effort, not merely to keep open, but also to expand, what remains a unique channel of East-West intercommunication. Towards this end, it is hoped that further Conferences will be held in England next year.

The forces that shape the embryo

T. GUSTAFSON and L. WOLPERT

How does a single egg grow into the immensely complex structure of an embryo? Recent work with the sea urchin has shown that only a few basic forces and mechanisms are required.

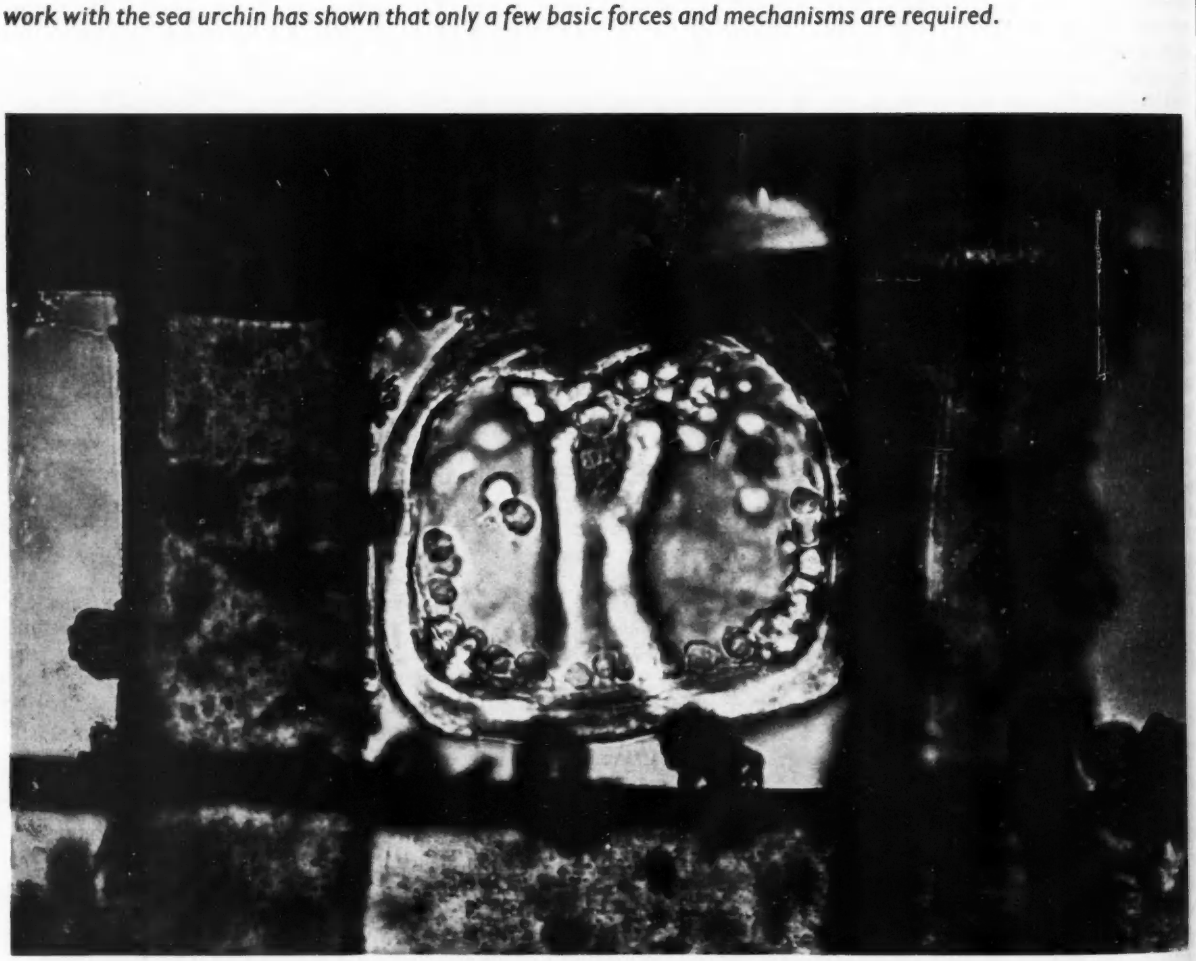


Fig. 1 Trapped in a nylon net to stop it swimming, a sea urchin larva at the gastrula stage when the gut is beginning to form. The sides of the mesh are about 150 microns long : the crystals of calcium carbonate on the net pin the larva in place. It can now be studied by time-lapse cinematography. Note the cluster of secondary cells at the tip of the invaginated gut, and the ring of primary cells at the lower pole.

"The general purpose of developmental physiology is to discover the 'forces' which form the shapes . . . to explain the development of form in organisms in as few and simple mechanisms as possible." Rouse, 1895.

A central problem in biology is to explain how reproducible, complicated, cellular patterns arise from apparently simple patterns. How does the apparently simple egg give rise to an organism of such complexity as a sea urchin larva or a man? While there has been much effort in tracing the biochemical patterns during development —for example, the time and location of protein and nucleic acid synthesis —nothing like the same attention has been given to the causal analysis of the forces which bring about the formation of cellular patterns, or how molecular processes operate in moulding the shape of an embryo.

So, while we have quite sophisticated ideas about proteins and nucleic acids, we have almost no ideas about how these are related to the cellular events that shape embryos; for example, we do not know how a cell sheet becomes curved or invaginated or stretched. This situation has arisen partly because of our incomplete knowledge of how cells behave during development and partly due to the emphasis on the biochemical aspects of development that has continued now for some 40 years.

While it is common practice in the physical sciences to look at the forces operating in various systems, this aspect of developmental physiology has been somewhat neglected. This is surprising in view of the current interest in biophysics and the emphasis by the early workers on redevelopment, particularly Rouse (the author of the quotation above) and His in the last century, in finding the forces which shape the embryo. Also the discussion of physiological processes—for example the heart beat and circulation—in terms of physical forces is standard practice.

Any change in form of a system, either physical or biological, requires forces to bring such a change about and it is these forces and their organisation in a developing embryo in which we have been primarily interested. In looking at such forces we have hoped to discover some of the basic processes in shape formation, and we consider this a prerequisite for asking the correct biochemical questions so that the link between morphology and biochemistry may be established.

In making such an analysis we have sought wherever possible to simplify and reduce to a minimum the amount of information required to specify a morphogenetic process. By doing so one also reduces the biochemical complexity that must be sought for, when the origin and organisation of the forces is investigated. We have always invoked Occam's Razor by choosing the simplest hypothesis, and by preferring mechanical and geometrical explanations to ones involving some special biological principle.

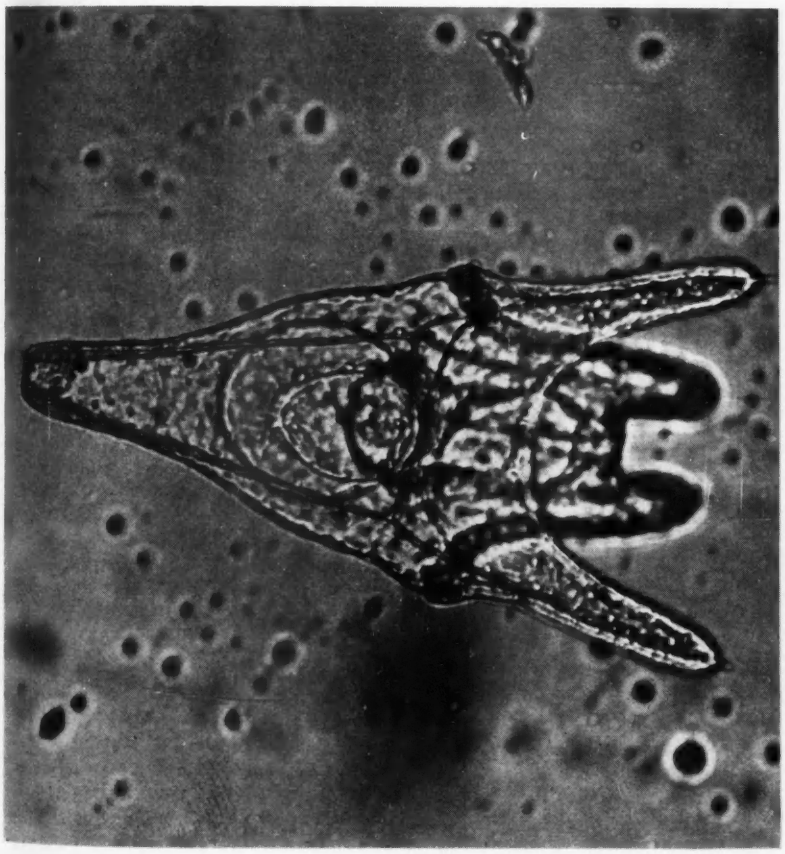


Fig. 2 Here the sea urchin larva is seen at a much later (pluteus) stage, viewed from below. On the right (ventral) side four arms have been extended by the rods of the skeleton: on the left (dorsal) there is a similar single extension. The large circular structures are the stomach.

The sea urchin embryo

The system we have concentrated on is the early development of the sea urchin embryo. The choice of this animal is a matter of convenience: its development is well studied in other respects (for example, biochemistry); the embryo is transparent; the cell sheets comprise but a single cell layer; and it develops during two days into a quite complicated — but not overwhelmingly complex — free-living and rather beautiful larva *(see Fig. 2)*. In this study we have made much use of time-lapse cinematography which, by speeding up the development, allows one to detect movements almost impossible to see at a normal time scale and also allows continuous observations of selected cells.

The application of time-lapse cinematography to developing sea urchin larvae raised some technical problems, as the larvae begin to swim very actively about 10 hours after fertilisation. This difficulty has been overcome by trapping the larvae in the meshes of a nylon net on which crystals of calcium carbonate have grown. The crystals make small indentations in the larvae and keep them in a constant position without interfering with their normal development *(see Fig. 1)*.

It is convenient to outline first very briefly the main features of the development of the larva (*see series of drawings in Fig. 3)*. After fertilisation the egg undergoes a series of cell divisions —about 10—and comes to form during the first 10 hours a hollow sphere—the blastula—whose wall is one cell layer thick and consists of about 1,000 cells (*Fig. 3d*). On the outer surface there is an elastic and plastic layer, the hyaline membrane. Throughout this period, and even in the unfertilised egg, the embryo has a polarity to which the development of the various organs are related.[1] It is convenient to denote the region at the lower (vegetal) pole as zone 1, that slightly more towards the upper (animal) pole as zone 2, and the uppermost zone as 3.

After a few hours the cells (40-50) from zone 1 enter the blastocoel, and move about on the blastula wall. These cells—the primary mesenchyme cells—come to take up a well defined position on the blastula wall, in the form of a ring with two branches extending towards the upper pole (*see Figs. 3e-g, and Fig. 8*). It is a profoundly important morphogenetic problem how these cells come to take up this position and how their movement is directed.

The next stage is the formation of the gut (archenteron) and is known as gastrulation *(Fig. 3e-3l)*. This involves the invagination of the cells in zone 2, which become extended as a tube-like sheet into the blastocoel,

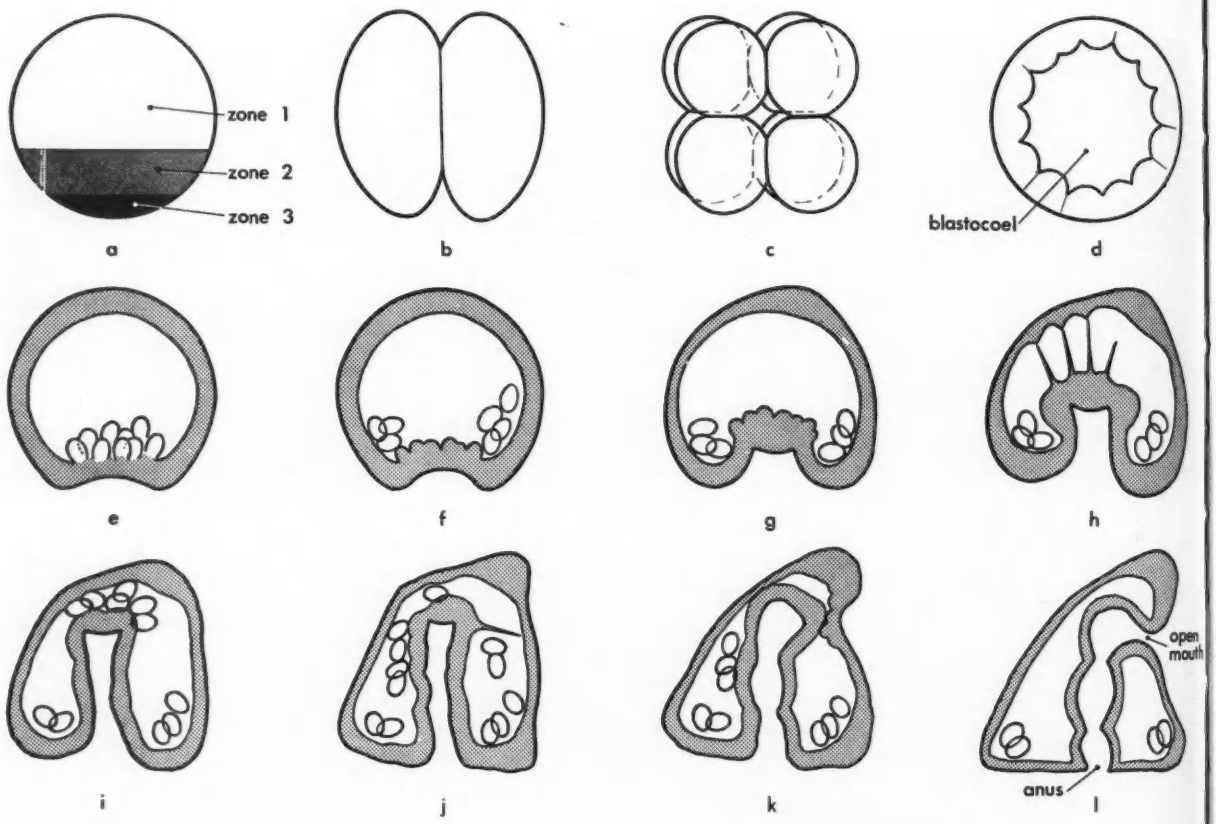


Fig. 3. The early development of the sea urchin embryo, from the unfertilised egg (a) to the formation of the mouth and gut (l). The main stages in development (which are discussed fully in the text) are the formation of the hollow sphere-like blastula by repeated cell division (a—d); the entry of the primary mesenchyme cells into the blastocoel (e) where they form a well-ordered ring (f—h); the formation of the gut by invagination of the ectoderm (starting at e); the flattening of the larva wall on the lower and ventral sides (starting at g) and the development of secondary mensenchyme cells (i) and pseudopod extensions (h onwards) which pull the gut upwards. Zone 1 gives rise to the primary mesenchyme cells, zone 2 to the secondary mesenchyme, zone 3 to the ectoderm. The above drawings are not to scale.

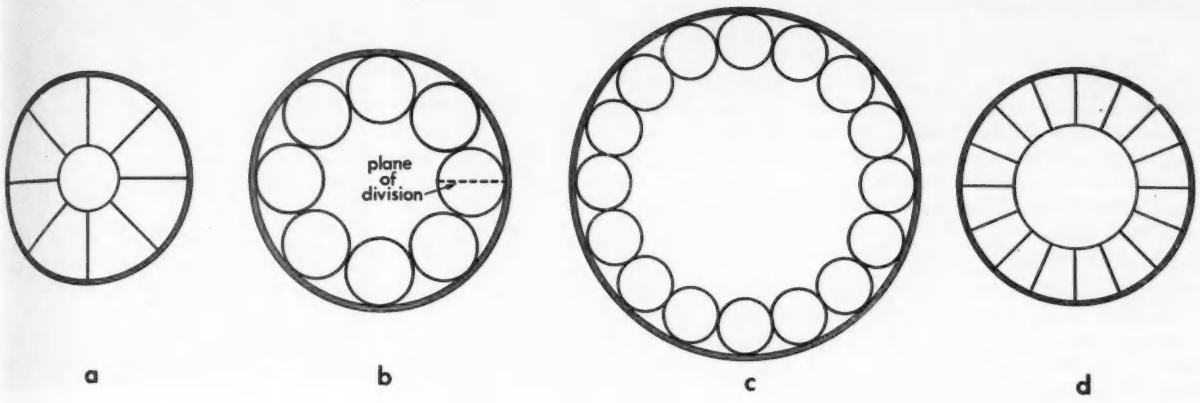


Fig. 4. A model of a cell sheet in the form of a tube to show the simple geometrical mechanism of blastula formation. In (a) the eight cells have good contact with each other. In (b) the cells have rounded up prior to cell division—this reduces the contact and the volume increases. The cells divide to form the 16-cell tube in (c), causing a further volume increase. After division the cells relax and again increase their contact with each other (d), thus causing a slight shrinkage. There have been many attempts to explain these volume changes.

rather like poking a finger into a balloon. This lower opening will form the anus. The tip of the invaginating region eventually comes to make contact with the wall of zone 3 (ectoderm) in a specific region near the upper pole, on the ventral side *(Fig. 3k)*. Its fusion with the ectoderm there, together with perforation of the two sheets, gives rise to an opening, the mouth. We shall examine how this directed translocation of a sheet of cells is brought about. The gut does not remain as a simple tube but becomes subdivided by a series of constrictions into coelome, oesophagus, stomach and proctodeum. The coelome is subdivided and comes to lie to the right and left of the mouth.

While the gut is being formed changes are occurring in the ectoderm. The wall flattens both at the lower pole and at one side—the ventral *(Fig. 3g-3j)*. The basic form of the larva is now evident. Later, the skeleton which is laid down by the primary mesenchyme cells extends the ectoderm at five points, four on the ventral side and one on the dorsal side. This gives rise to the arms and the typical Eiffel tower shape of the larva *(Fig. 2)*. We are fortunate that in this system there is little cell division after blastula formation, and that there is no growth (that is, increase in organic material) during development. This considerably simplifies the analysis.

In considering these changes we will confine ourselves to four main types of change in form: (a) the formation of a hollow sphere—the blastula; (b) the changes in curvature of a cell sheet as shown by the ventral flattening; (c) directed movements of cells as shown by the primary mesenchyme cells; and (d) directed translocation of a cell sheet over a considerable distance as shown in the formation of the gut.

In attempting to explain these processes we shall make use of two main principles: (a) pseudopod formation by cells, and (b) the changes in the contact relations between the cells, probably reflecting *changes in adhesion* between them. The variation in these two cellular activities in time and space can bring about profound changes in the shape of the embryo.

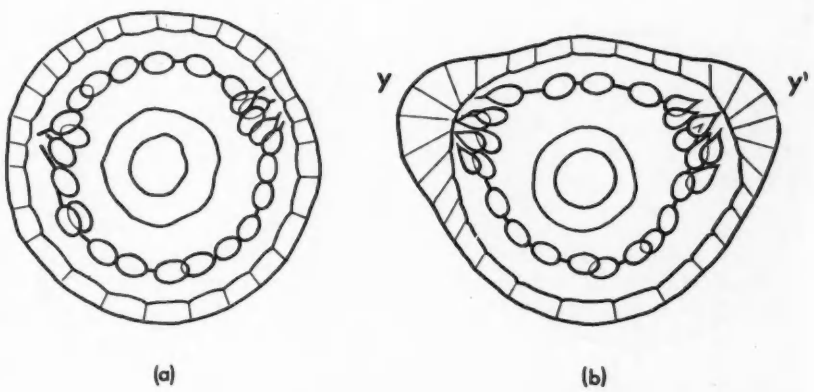


Fig. 5. Thickening and curvature : diagrams of the gastrula stage showing the flattening of the ventral side (uppermost) seen from below. When the gastrula changes from the rounded form in (a) to that in (b) there is an increase in thickness and curvature of the walls at Y and Y^1. This is probably due to an increased contact between each cell. At the points where the contact between the cells in the wall is greatest, the primary mesenchyme cells tend to accumulate.

Forming the spherical blastula

The formation of the hollow sphere-like blastula is the first process in development in which the cells take up a well ordered form, and we may ask why successive divisions of the egg should lead to a hollow sphere rather than a random compact mass of cells. We have argued that this can in the main be explained in terms of mechanical and geometrical considerations. The plane of division of the cells is not random but appears to be always radial, and this, together with the fact that the cells adhere very strongly to the hyaline membrane, can provide the basis of an explanation if we examine how the cells are packed.

Look at the idealised model system in Fig. 4a in which eight cells form a tube. At division the cells round up, probably due to an increased tension in the membrane, reduce their contact with each other, and thus force each other apart. This increases both the internal and external volume of the tube and if these rounded cells are now divided radially into two similar rounded cells of similar volume, and still remain in contact with the supporting hyaline membrane, then for purely geometrical reasons, the tube volume will increase still further. After division the cells "relax" and increase their contact with each other, which leads to a small reduction in tube volume.

We have found the embryo during blastula formation to behave in just this way—at each division the volume increases and after division there is a small reduction in volume. It does not seem necessary to postulate that somehow the blastula is "blown-up" by water entering the blastocoel as has been suggested by other workers.

The geography of changes in shape

The later changes in the shape of the more or less spherical cell sheet do not depend on cell division. For

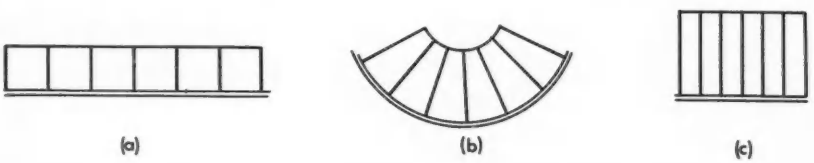


Fig. 6. The simple mechanism which underlies curvature and thickening. In this model, a sheet of cells is attached to a supporting membrane (a). If the cells increase their contact with each other without loss of contact with the supporting membrane, the sheet must become curved and thickened. If the cells can lose contact with the membrane they will become columnar.

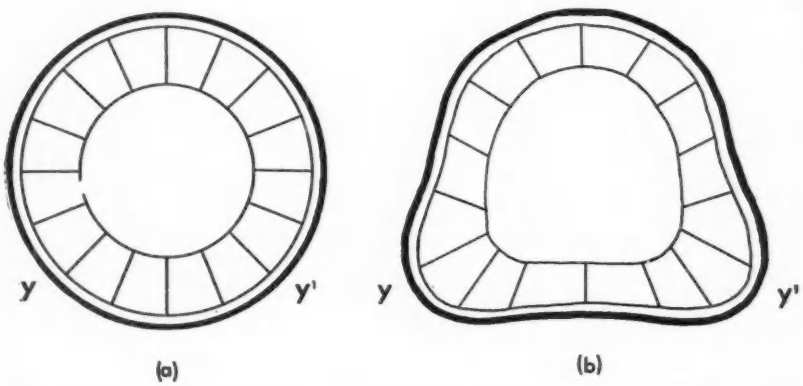
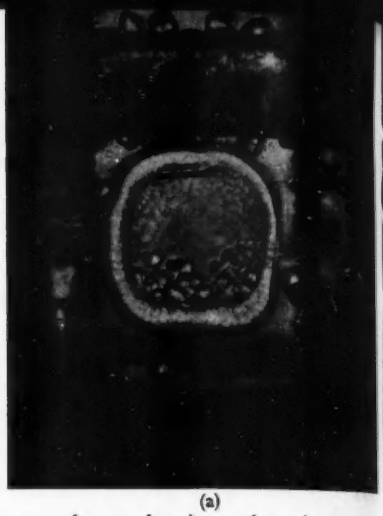


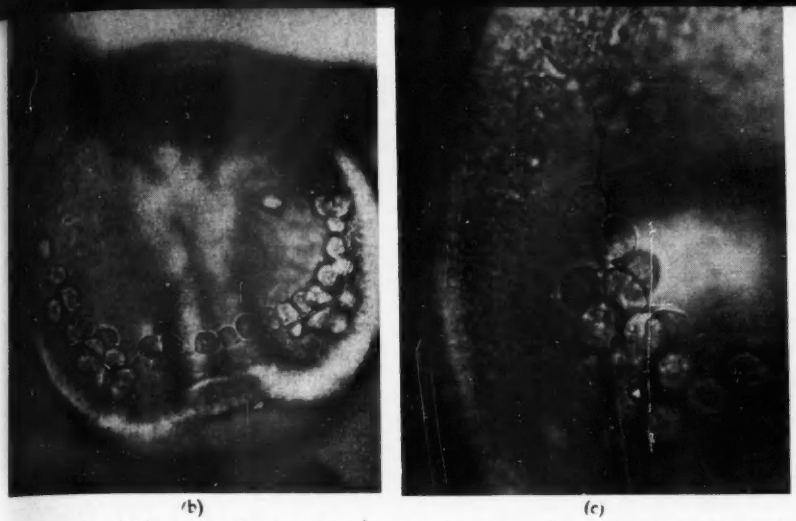
Fig. 7. The model shown in Fig. 6 is here curved round to form a tube structure (a). This is comparable to the drawings of the gastrula stage in Fig. 5. If there is an increase in contact between cells at Y and Y^1, without loss of contact with the supporting membrane, then the tube must change to the shape shown in (b). This model assumes that the internal volume of the tube remains constant. Note the thinning of the cells adjacent to the thickened regions.


(a)

example, at the time when the gut is invaginating, the wall begins to show variations in thickness and curvature (*see Figs. 3g-l and 5*). There is an increase in the thickness and curvature in a ring around the ventral side (which gives rise to the main ciliated band) and this is associated with the flattening of the ventral side and a thinning of the cell sheet in the adjacent regions in Fig. 5. This changes the overall shape of the embryo from one that is sphere-like to one with pronounced dorso-ventrality which is like a triangle in side view (*Fig. 3l*). There is also an especially great increase in thickness at the ventral side at the upper pole.

One way of looking at this change in shape is to regard it in terms of changes in curvature in a cell sheet, which initially has a more or less uniform curvature. It is clear that the increased curvature occurs where the cell sheet becomes thicker, and it is possible to explain the changes on this basis.

Look again at a simplified system—an array of six adjacent cells which are attached to a supporting membrane (*Fig. 6*). If the contact between the cells were to increase, and the contact between the cells and the supporting membrane were to remain constant, then the sheet must become curved as in Fig. 6b. This is a simple geometrical requirement. If, on the other hand, the cells could reduce their contact with the membrane, then the cells would become columnar as in Fig. 6c. Expressed in another way, an increase in the adhesion between cells, tending to increase the contact between them, could lead to an



(b) (c)

Fig. 8 Photographs of sea urchin larvae to show the change in distribution of the primary mesenchyme cells. At (a), when they have just entered the blastocoel, they are more or less at random ; in (b) they have formed a well-ordered ring with two branches (seen here in ventral view). Compare this with the drawing in Fig. 5b ; note also that a few skeletal rods have been laid down by the primary mesenchyme cells, orientated along the ring. In (c), taken at a higher power, the first pseudopods formed from the cells are visible: shortening of these pseudopods moves the cells.

increase in thickness and curvature in the sheet if the adhesion of the cells to the supporting membrane is so great that no reduction in contact occurs.

We thus suggest that changes in contact between the cells may be responsible for the above changes. This may be seen in the model system in Fig. 7. If cells in the regions Y and Y^1 were to increase their adhesion in the above manner, and the internal volume of the ring remains constant, then the ring will take up a form as in Fig. 7b which appears analogous to the ventral flattening.

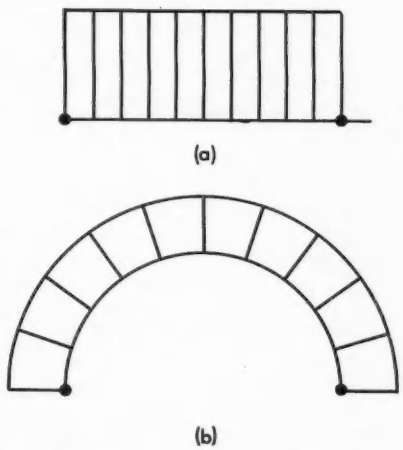
While we have no direct evidence for this mechanism—for example, from measurement of the forces of adhesion —there appears to be a constant association of increased thickness with increased curvature. Also a strong adherence of the cells to the hyaline membrane, already mentioned in connection with blastula formation, is indicated by the fact that the cells never show any pulsatory movements on the surface in contact with this membrane, but slow pulsations may be seen on their inner surface.

Pseudopods and cell movement

The mechanism described above cannot account for long range translocation of cell sheets as in the formation of the gut. This requires forces of a different nature and in the formation of the gut these are provided by a pseudopodal mechanism. We must thus examine pseudopodal activity and this is well illustrated in the migration of single cells—the primary mesenchyme cells.

The primary mesenchyme cells form from zone 1 of the blastula wall. Their entry into the blastocoel is accompanied by considerable pulsatory movements or bubbling of their inner surface, which, we think, reflects both their loss of adhesion with the adjacent cells and the hyaline membrane, and their tendency to round up. They are thus squeezed into the blastocoel. After they have entered the blastocoel they form an irregular pile, and it is now that their behaviour seen under high power magnification becomes most dramatic.

Long processes — pseudopods — are shot from the cell surfaces into the blastocoel. Each cell may have several pseudopods. When these make good contact with the wall their contraction brings about the movements of the cell, drawing it towards the point where the attachment is made. When no good contact is made the pseudopods are withdrawn into the cell body. Due to the action of these pseudopods the cells become dispersed on the lower half of the blastocoel wall in a manner which shows no clear pattern *(see Fig. 8a)*. However, the cells soon begin to take up quite a definite pattern—that of a ring with its two branches *(Fig. 8b)*. This phase, as previously, is associated with the continuous formation of pseudopods which explore the wall and continually make and break contact with it *(Fig. 8c)*.



(a) (b)

Fig. 9. The mechanism for gut formation. A sheet of columnar cells will become curved or invaginated if the intercellular contacts are reduced and the ends of the sheet are fixed.

How then, does this ordered pattern arise? We have suggested that the formation of the well-ordered pattern from the dispersed state does not require any special guiding mechanisms such as chemotaxis or pre-laid pathways, but may simply reflect the development of a pattern of increased adhesiveness within the wall such that the pseudopods make more stable contacts in such regions. The presence of regions of increased adhesiveness on the wall, such that pseudopods make the most stable contacts there, will eventually lead to the cells accumulating in such regions due to their random exploration followed by contraction. It is clear that in the competition between the pseudopods, those which make the most stable contacts will "win." Thus the blastula wall acts as a "template" in determining the pattern of distribution of the primary mesenchyme cells. It is rather like shaking balls on a board with holes in it: the balls will take up the pattern of the holes as they become trapped. The possibility of such a mechanism for directed movements was first suggested many years ago by Weiss[2].

The pattern of the distribution of the cells is very similar to that seen in

the ectoderm when it thickens — the cells tend to accumulate in general at just those regions where the adhesion between the ectoderm cells appears highest. This correlation suggests how morphogenetic processes may be co-ordinated.

A feature of particular interest in this process of pattern formation by the cells is the lack of precision shown in the whole process. The detailed movements of individual cells in different larvae is very varied. The pattern of movement is not fixed or determined and the final result may be reached by a wide variety of pathways.

Forming the gut

Turning now to gastrulation—the formation of the gut by zone 2, which involves a long range translocation of a sheet—it is seen that the first phase involves a "bubbling" of the cells in a manner very similar to that shown by the primary mesenchyme cells when they enter the blastocoel. Again, this may reflect a loss of adhesion between the cells and their tendency to round up. In this case, however, the cells remain attached to each other and to the hyaline membrane and only reduce their contact with each other. The packing of the cells now becomes different and for mechanical and geometrical reasons, an invagination must occur.

Consider the model system comprising a cell sheet in Fig. 9. If the ends are fixed and the cells tend to round up, reducing their contact with each other, then, in order to accommodate their new shape, the sheet must become curved. This mechanism can only bring the cells a limited way across the blastocoel and something further is required. This is provided by pseudopods that are shot out from the cells at the tip of the invaginating region (*see Figs. 3h and 10*).

These pseudopods, like those of the primary mesenchyme cells, also "explore" the blastocoel and its wall. When they make contact with the wall their contraction pulls the gut further into the blastocoel. The force of their contraction may sometimes be indicated by the cones which are drawn out from the wall where the pseudopods attach to it. There is generally a pause between the first and second phases of invagination, as indicated by the plateau in the invagination-time curve (*Fig. 11*). The second phase is always associated with the formation of pseudopods, and the pause suggests that invagination cannot proceed until pseudopods form.

When the gut has been pulled almost to the upper pole the cells at the tip pull themselves out probably due to their loss of adhesion with the adjacent cells and the hyaline membrane, and enter the blastocoel. The pseudopodal activity of the tip does not cease since the cells left behind now begin to show the familiar pattern of pulsatory movements followed by pseudopod formation. These pseudopods again explore the blastocoel and its wall and appear to make the best contacts with the future mouth region on the ventral side and thus draw the gut tip towards this region (*Fig. 3j*). This is a fine example of directed translocation and is explicable in just the same terms as pattern formation by the primary mesenchyme cells. In this case the region of stable contacts would be the future mouth region.

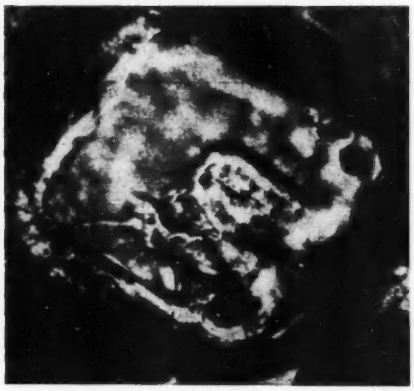


Fig. 10. During gut formation pseudopods form at the tip of the gut and attach themselves to the wall. They then draw the invaginated gut up through the blastocoel.

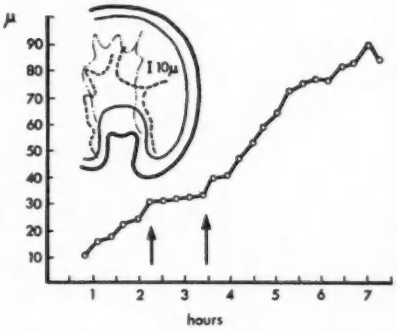


Fig. 11. The progress of invagination plotted against time. The first phase, which is associated with pulsatory activity at the tip of the gut, stops at the time indicated by the first arrow. The second phase, starting at the second arrow, is associated with the formation of pseudopods.

These observations taken together with those on the primary mesenchyme cells suggest that pseudopodal mechanism is particularly suitable for morphogenetic movements as it provides both a mechanism for long range translocation as well as a means of finding the region to which the cells must be translocated. This mechanism has further application in other aspects of sea urchin development (for example, coelome formation) and there is some evidence for its operation in other animals—for example, tracheole formation in insects as shown by Wigglesworth.

The region of the future mouth undergoes an invagination very similar to that seen in the primary invagination of the gut with pulsatory movements of the cells and decreased contact between them. The invaginating ectoderm and the gut tip fuse, and due to both mechanical forces exerted by the pseudopods, and possibly an enzymic action originating from the tip, the two cell sheets become perforated, giving rise to a mouth (*Fig. 3l*). Water can now flow through this mouth, down the gut and out of the anus which is where the first invagination occurred.

The time pattern of the basic forces

The above results suggest to us that many of the features of sea urchin morphogenesis can be accounted for in terms of variations in but a few basic cellular activities, in particular pseudopodal activity, pulsatory activity, and changes in contact relations (adhe-

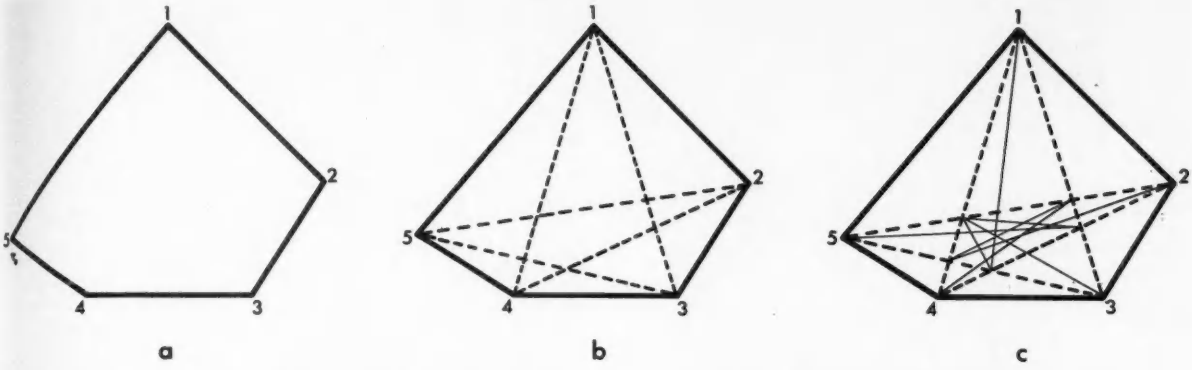


Fig. 12. The formation of a self-complexing system. By one simple rule governing the way lines should be drawn inside the polygon, a highly complex pattern can quickly be built up. The rule is to join any corner or intersection to any other.

siveness). What determines the morphogenetic event may be the distribution of these activities in space and time. The activities themselves are probably related in that high adhesiveness between cells which is never associated with pulsatory activity or pseudopod formation. In fact it may be possible to grade the activities of all the cells according to but one or two basic parameters.

Not only are the basic cellular activities concerned relatively simple, but also the pattern of their activity. For example the pattern of activity in the gut shows a graded activity both in time and space. The time of development of the cellular activity is graded in that it starts in the lower pole and gradually spreads upwards. Also, as one moves from the lower to the upper pole, so is the pseudopodal and pulsatory activity reduced, and the tendency for the sheet to maintain its integrity with good intercellular c o n t a c t s increased. These graded patterns of activity are very suggestive, and it may be possible that they are related to the biochemical gradients known to be present in the embryo.

We hope that in the above discussion we have been able to show how relatively few cellular activities may be responsible for bringing about a wide variety of changes in form in a developing embryo. Pseudopodal activity and changes in contact between the cells can provide, in the sea urchin at least, an explanation of changes in curvature in cell sheets, directed movements of cells, translocation of cell sheets (as well as the pattern of the skeletal rods which has not been discussed here). The principles are very simple and while at this stage we cannot be sure what more complicated factors are involved, they may show the usefulness of mechanical and geometrical considerations. Even when other factors are revealed, such principles must certainly play a great role. The application to other systems remains to be investigated.

Complexity from simplicity

This analysis merely leads one to further problems and one must now pose two main questions. What is the molecular basis of these activities? And what determines the pattern of activity both in space and time? While there is renewed interest in the molecular basis of cell movement and cell contact[3], and much remains to be done, it is the second question—what determines the time-space distribution of cellular activities? — that is at the moment the most perplexing problem.

For example, we have seen that it is the pattern within the ectoderm that is responsible for much of the complicated form of the embryo, especially in so far as it provides a "template" for the pseudopods. The origin of this pattern is almost completely unknown. Also we do not know what determines the borders between the various cell types—for example, how only a limited number of cells form zone 1, the primary mesenchyme. It is not only the spatial distribution of cellular types and activities that presents a problem, but we must also ask how their activity is a r r a n g e d in the correct time sequence. Even more puzzling is how such patterns become more and more complicated as development proceeds, and we can find no evidence for these patterns in the unfertilised egg. The system thus seems to be "self-complexing."

While these p r o b l e m s remain unsolved we believe that the original pattern within the egg may be quite simple and that small differences can provide the basis for larger differences, which themselves provide the start for yet further divergencies. A simple set of rules may lead to complicated patterns. As an example of a self-complexing system we offer a trivial, but perhaps instructive example. If one has an irregular polygon and one gives the simple instruction to connect all junctions between lines, a quite complicated pattern of lines results (*Fig. 12*). While this is only a game, one must not despair that one may find simple rules for the development of complex patterns in embryos.

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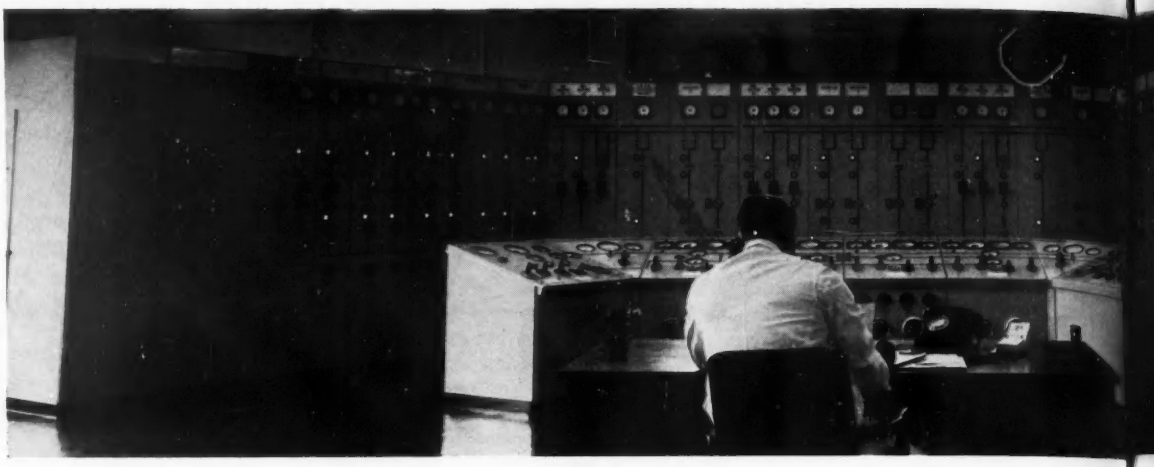


The remaining barriers to a

Even in the processing industries such as oil refining there is as yet little automation, though automatic control is already well established. What are the road-blocks to full automation?

The process industries, in particular the oil and chemical, employ a huge amount of capital, much of it tied up in the elaborate metallic architecture of the process plants themselves. One of the main factors influencing the return on this capital is the *efficiency of the control procedures* on the individual units. This article is an attempt to outline a fresh approach towards using modern control methods to increase the efficiency of control procedures, and hence the earnings of invested capital.

Most attempts to systematise control procedures, which is a necessary prerequisite to automation in any form, have had to recognise that a substantial part of the present level of control knowledge is locked up in the art, judgment, skill, and especially experience, of the plant operators. And doubt has been expressed that any machine system can have similar prescience of what control adjustments are required at any given time. The tendency has therefore been to analyse the complex physico-chemical relationships, and to defer any systematisation of the control problem until such knowledge is available. This in turn has precipitated a requirement for more comprehensive instrumentation and higher instrument accuracy all round.

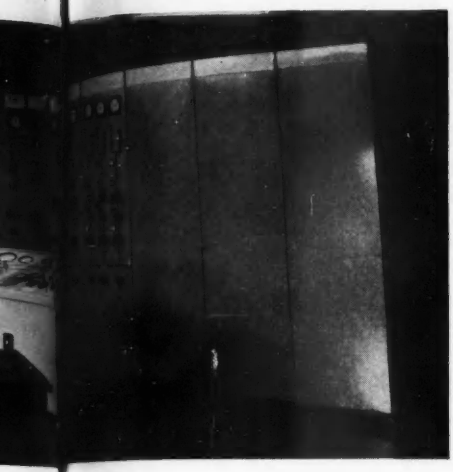
If any measure of automation is to wait on the results of such an approach, then the fact has to be faced that there is going to be a very, very long wait, and such a decision is tantamount to deferring automation for an indefinite period. It is very doubtful, however, if such a decision is really necessary, and for the following reason: many millions of tons of marketable products conforming to a wide variety of specifications are in fact produced now by the process industries.

In other words, incomplete as our present understanding may be, it is certainly not ignorance. Obviously better instrumentation and understanding will help, and efforts should continue to this end, but it is not a prerequisite. The problem is how to make the present state of control knowledge explicit, so that it can be substantially measured, systematised, and eventually engineered. So far, the solution to this problem has been the real barrier to progress but a more direct approach can now be described.

Human control

The capability practised by all competent plant operators is that of putting the plant in a very definite operating state, namely one where the product is "on specification", or "off specification", or some precise sub-classification of these two conditions. These operating states are objective and measurable, for usually a well-prescribed laboratory test is used to measure them.

The means whereby an operator achieves this is to make a *selection of the settings of various instruments*, and it has to be admitted that either this



to automation

L. C. PAYNE

selection is better than chance or it is not. If it is not better than chance, then any random setting will suffice, and there is no problem in automating, for machine-systems selecting according to chance are straightforward to engineer.

On the other hand if there is selection better than chance (as is always claimed) then the nature of this selection can be determined, and it is thus possible to associate with each objective (measurable) state, a particular (measurable) selection of instrument settings. It may be true that different operators, and the same operators at different times, make different selections for the same state (since it is well-known that there is not simply a unique set of values) but these selections must be highly correlated since each determines a precise, measurable state of the product. One can therefore assert that the present state of control knowledge as exercised by the human operators manifests itself explicitly and measurably in a selection (of the instrument settings) better than chance.

Finding these selections of course requires a suitably designed scientific investigation, about which more is said below, but it may be of interest to report that in studies already proceeding, there is strong indication that in the widely practised distillation process only a handful of process variables appear to be important in differentiating one operating state from another. Moreover the accuracy requirements are a bye-product of such studies, and they differ for each process variable, a fact which should mitigate against prejudging the accuracy requirements for automation.

Investigations are expensive : they consume time, energy and effort which could otherwise be earning, and they may tie up a plant and special equipment which could also be earning. Moreover they may achieve little unless they are designed to establish clear and desirable objectives. It is useful, therefore, before particularising investigational methods, to formulate a clear concept of what is meant by automation, so that a precise statement can be made of what an investigation leading toward that end must provide. Like the words computer and operational research, automation has an emotional ring and is often used as a catchword to give an aura of prestige. However, unless it can, in advance of its introduction, be seen to be a profitable investment in the hard-headed commercial sense, it is not likely to go very far.

It is not difficult to show that automation is a much more general concept than what is usually implied by automatic control, which has existed for centuries ; it is also much more than mechanisation, which usually means the coupling together of a number of automatic machines. Fundamentally it is more comprehensive in its control capabilities, exhibiting a close similarity with much of what is regarded as intelligent human action—the reasons for which will be made clear. To clarify this important fundamental difference it is necessary to consider the essential nature of control and then attempt to see how it can be systematised—a prerequisite for automation of any sort. All control, automatic or not, *involves a flow of information* between what is controlled and what is controlling. This is as true of driving a car, as it is of guiding a missile, or managing a business.

Single information channels

Automatic control almost invariably refers to a control system involving *a single information channel.* For example, a temperature controller (thermostat) takes in a measure of temperature, compares it with a pre-set value, and passes on the difference to activate fuel supply : a pressure controller similarly provides information to activate a valve controlling pressure, and so on for flows, levels, speeds, etc. These channels may be "open loop" or "closed loop", but in every case automatic control consists of a number of individual and autonomous "controllers", each having a single information channel, one for each variable controlled (*see Fig. 1*).

This is substantially how an oil refinery process, a chemical process, a baking process, or a power station, and so on, are controlled under a system of automatic control. The control room consists of a number of so-called automatic controllers, one for each process variable, as described. The human operator adjusts the "set-point" of each controller to some selected value, which then, like the thermostat, automatically adjusts itself to the setting. Evidently the essence of the human operator's task is to make *a selection of the set points* so that the overall process yields a product conforming to a given specification ; he must of course change this selection as process conditions vary (for example, weather, raw material, flow-rates, and so on) to maintain the product within specification limits (*see Fig. 2*).

However, this is *not* automation. Automation is not specifically concerned with controlling particular variables but rather with adjusting the *overall system response* so as to maintain the process objective. This objective may itself be flexible to cover a range of product specifications. An automation system is characterised by the fact that several, perhaps many,

variables are required to measure adequately the actual state of the system one is trying to control. For example in an air traffic control system, the air situation will be transduced by radars, navigational systems, data links, and the like ; in an oil refinery unit the state of the plant will be transduced by pressures, temperatures, and flow meters ; or in a management task the relevant business environment will be transduced by all the associated paper transactions.

This ensemble of data from all inputs is then routed through various processing ("decision") channels before issuing at one or, usually, several action points which change the operating state of the overall system.

The information mesh

In an automation system of control the disjoint single information channels characteristic of an automatic control system are replaced by what may be termed an "*information mesh*", each cell of which constitutes a data-circuit and performs some ancillary control function. These circuits can be much more elaborate than the single data-circuit of automatic control, and moreover they need not be restricted by linearity considerations.

The information mesh (*see Fig. 3*) connects the multiple data inputs of the system (for example, column pressure and temperattre) to the multiple set of outputs which control the system. In the primitive case where only one input is required to describe the system (for example, temperature) and where only one action is required (for example, activating fuel supply) an automation system reduces to automatic control. The difference, however, is not simply a matter of degree, as the following remarks will indicate.

In an automation system it can be seen that a control action may result from *the conjunction of several information processing paths*, and this can never be the case in an automatic control system which comprises a number of disjoint single information channels. Thus a change in temperature (*see Fig. 3*) may result not only from what is determined by certain flows and pressures, but also, for example, by whether a checking "circuit" in the information mesh determines whether such a change would result in a temperature safety limit being exceeded.

Furthermore, it has already been pointed out that the necessary control action may involve not one variable but many, as one moves from one operating state (selection of instrument settings) to another desired state (selection of instrument settings) ; in this case information must flow throughout the mesh feeding each action point according to the *system* adjustments required.

Information redundancy

The similarity here with human behaviour is real : not only is a certain action (or decision which may require multiple actions) determined by relevant data from various sources, but over and above this, additional information is solicited to check the safety (or wisdom, or ramifications) of the action, and this latter can be designed to have an inhibiting or some other effect. In either case multiple information channels determine the action. Since no equipment is infallible, and since 100% safeguards are required against harmful actions, then clearly this can only be achieved by using information "redundancy", that is, allowing a conjunction of information paths, supplying more information than is strictly adequate, to determine an action. This an automation system allows.

In any activity if one has perfectly reliable information and perfectly precise rules (that is, adequate theory) then there is no need for information redundancy. This is the case substantially with mathematics and computation ; there is no problem here in defining the information mesh : it is characterised by the equations. In such an activity one can say that the mesh processes information with very high efficiency : actions can be related to input data precisely. Other types of activity may only admit of statistical systematisation leading merely to probabilistic (that is, less than certain) recommendations for action ; these therefore require extra "redundant" information to guard against possible wrong actions of small, but real probability. The corresponding information mesh would process with less efficiency, but be compensated by redundant information.

Further down the scale one relies on even looser systematisations such as rules of thumb, and large quantities of redundant information are required ; it is these latter cases where "experience" and "feel" are said to be, and obviously are, important. Experience it is which supplies a large reservoir of additional information to protect an action from too naïve an application of rules of thumb.

It can be seen at this point why any gain in fundamental understanding helps : it refines the systematisation and allows a higher efficiency of information processing. But it can also be seen that its absence can be balanced by additional data, and does not mean that a mesh—and hence automation—is impossible.

From such remarks it will be evident that the kind of information mesh appropriate to any activity will depend on the nature of the activity ; *it is the purpose of an automation investigation to establish what type and amount of systematisation is appropriate, and what types of redundancy are needed to compensate ;* in other words to establish the relevant information mesh. Herein lies the real power of an automation system ; and herein lies its difference from automatic control.

The problem of systematising experience

It has been said with remarkable accuracy that intelligent action constitutes selection (from information received) better than chance. For example the immediate information to hand may be the current configuration of pieces on the chess board (or may be the current state of the instruments on a distillation unit). The situation will admit of several choices of action, partially but not completely limited by the rules of the game (constraints of the plant). The selection will be narrowed by invoking the additional information of experience to weigh and assess each move and its ramifications (in the case of a plant this can be measured by data-logging and analysing the selections as described earlier). If this still yields more than a unique action then more than one move (decision) is possible. Put round another way, there is no further information to

favour one selection (decision) rather than another.

This procedure has its counterpart in every type of decision ; only to the extent that the information supplied by experience can be measured and systematised is automation possible. This is almost inevitably confined to more elementary actions practised often in similar circumstances, such as plant control, where statistical evidence embodies the current level of control knowledge in a measurable form. Nevertheless the scope here for greater efficiency, and hence productivity, is tremendous.

To sum up, all control involves a flow of information between what is controlled and what is controlling. The kind of information systems with which automation can deal are of a different order of sophistication than the disjoint single channels of automatic control, and approximate closely in character to much of what is called intelligent action.

A prerequisite to automation is an investigation to establish an appropriate information network ; this may involve mathematics and statistics if suitable theoretical knowledge exists, but it may have to start from the level of systematising the activity at the operator's level if it does not.

The limits to automation

The limits to which automation can be applied are the limits to which the systematisation of human activity are possible and profitable. It should be said right at the start that in few cases is the systematisation likely to be complete ; that is, in few cases will it be both possible and profitable to automate entirely. Being realistic, what is likely is the replacement of a man-machine system by a man-machine system of greater control capability, at least to the extent of offsetting the extra capital investment.

This point emphasises the need at all times to consider retaining the human being in part of the selection process described above. It is likely that his present activity of staying on specification will be replaced by staying on specification at less cost, with a product producing a higher yield by operating safely and consistently on finer tolerances ; and also of being able to get

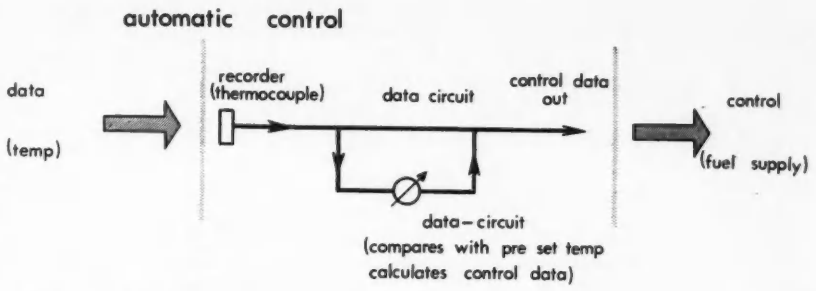


Fig. 1. Automatic control : a single information channel.

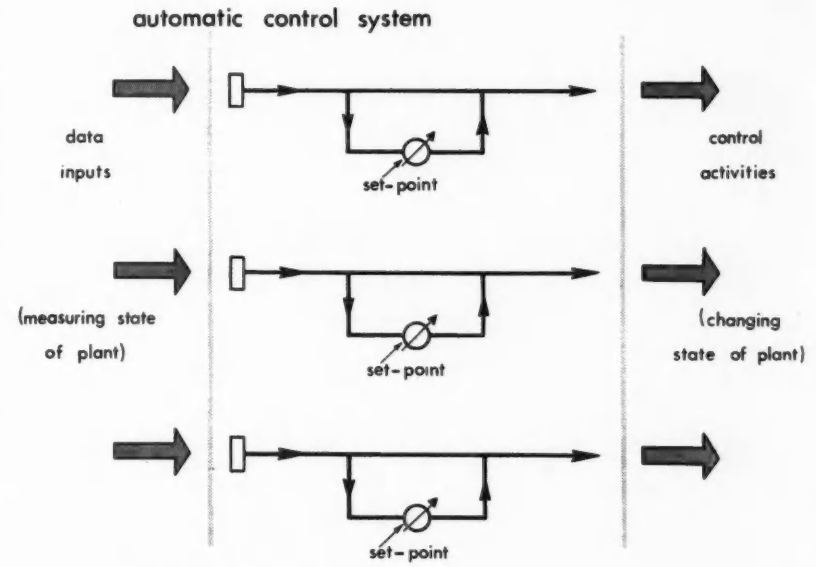


Fig. 2. Automatic control : multiple channels.

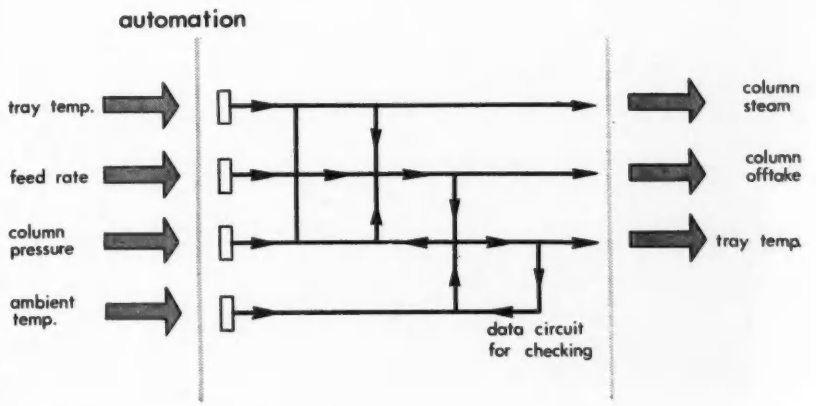


Fig. 3. Automation : an information mesh

on to specification, and alter specifications more quickly. Not least will be his contribution to emergency breakdowns of the type which are too rare to warrant elaborate instrumentation and processing equipment, and are better dealt with by a simpler automatic monitoring and alarm system.

However, what can be done, and what cannot be done, are not to be pre-judged. What can be done by a machine is what can be formally systematised ; what cannot be done by a machine is what cannot be formally systematised. Obviously systematisation is a key-word and some further discussion of it is necessary.

The application of scientific method

Science as it is commonly apprehended is the systematisation of human knowledge. This activity requires the formulation of concepts, such as mass, force, space, genes, and so on, which can be integrated into a logical scheme from which the facts of experience are formally deducible. Science proceeds by observation and measurement to the construction of hypotheses ; it then seeks further ramifications of these hypotheses to see if they accord with further observations so that theory can be extended and refined. By such means diverse happenings in time and place can be closely knit into a framework of consolidated knowledge which is readily understood and communicated. It is of the essence of such knowledge that it is explicitly formalised ; it asserts that if such and such is carried out under such and such conditions then certain measurable results will occur. It is independent of opinion or conjecture ; it can in fact be engineered.

From such a viewpoint science is essentially a research or backroom activity. But the scientific method need not be so confined : when during World War II thousands of bombers had to be lifted off the ground each night, loaded, fuelled, briefed, and controlled, it was recognised that the scale of this activity would benefit by a rational, quantitative approach.

Scientists were brought in to observe and measure, to suggest that new procedures would achieve measurable results in less time, with less labour and less effort. By investigating each aspect of the activity quantitatively it was able to show, not by argument, but by brute stubborn fact, which bottle-necks were most acute, and by how much. In other words it showed that the scientific method can be applied to the systematisation of human activity as distinct from the systematisation of human knowledge.

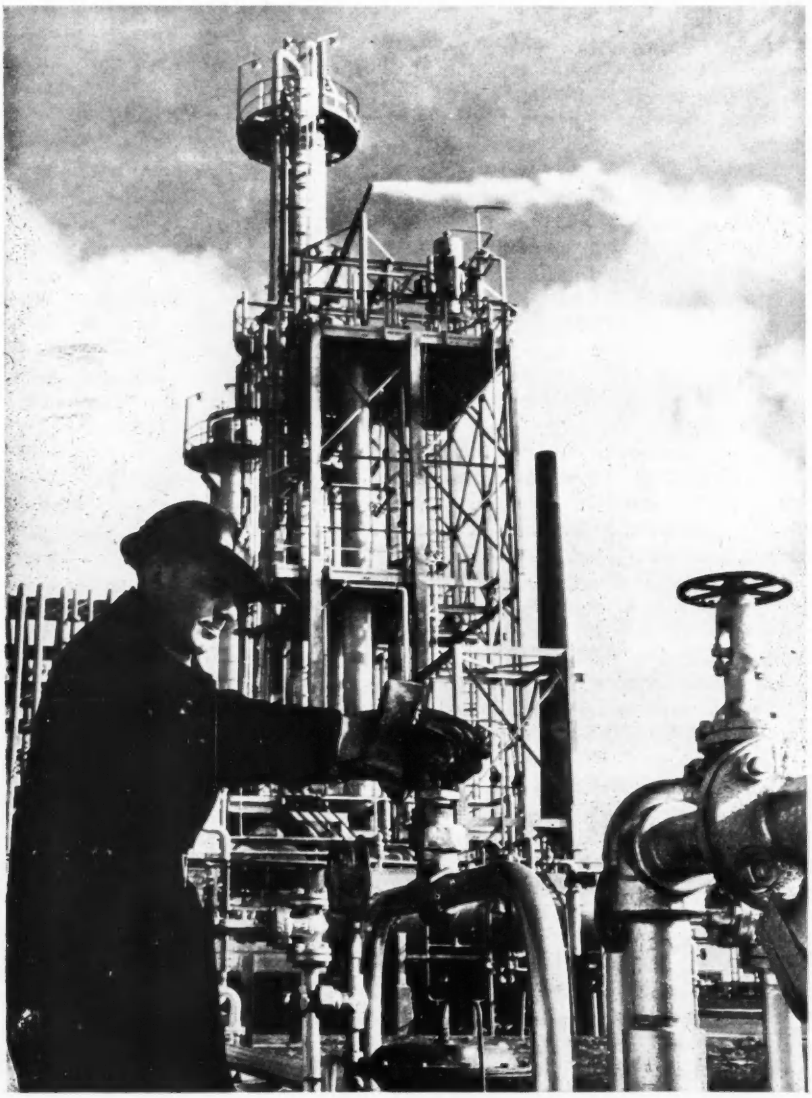


Fig. 4. A control valve from a catalytic reformer unit in an oil refinery: this is an example of a single control channel.

Industrial shortcomings

This view of scientific understanding is lamentably absent from British industry. It denies a wealth of ability which we have in quantity. Scientists are mainly regarded as impractical eggheads, and management as art, hunch and feel. If only the typical scientist were seen in his true light as someone competent in the scientific method but with a driving intellectual curiosity, then it would be possible to apprehend and encourage the scientist competent in the scientific method, but temperamentally disposed in a different way, namely towards human activity. The application of the scientific method

to systematising *human activity*, as distinct from *human knowledge*, is the best of what is loosely called operational research.

Operational research therefore is not magic, nor need it be mysterious. The type of systematisation required for automation is the establishment of the information mesh ; that is, to determine what ensemble of data in terms of accuracy and renewal rate is both necessary and sufficient to define a particular operating state of a plant, and to establish the manipulations of this data necessary to produce the multiple control actions.

The day-to-day operation of process plants, as distinct from the design, is virgin ground for the scientific method ; there is no shortage of intelligent conjecture or tentative hypotheses when adjustments are required on a plant, but by and large they are not followed up and the whole activity is conducted on an *ad hoc* basis. Feel, experience and personal assessment are the order of the day, and of course it works very well, but it would be surprising if a more scientific approach, quite apart from providing the essential prerequisite systematisation for automation, did not yield benefits in its own right.

Benefits of operational research

To quote from the Proceedings of the Institute of Radio Engineers (Jan., 1961), " . . . one of the most important impacts computers are producing in our society is through serving as a catalyst for channelling the attention of scientific and disciplined minds into relatively unformalised areas". It is not so much that there are not already highly disciplined minds in the process industries, but rather that the essential systematisation of specifically control information, required for the introduction of some measure of automation, provides both a focus and a stimulus for directing these energies along a useful path.

The same reference continues "When the channel is established, when the practitioner has overcome his fear of the machine, and when the scientist and practitioner are communicating, the attack is relentless. The scientific mind has found an unformalised field and it cannot rest until it identifies, understands and organises basic elements of the field : the practitioner has found a powerful new tool to advance his capabilities."

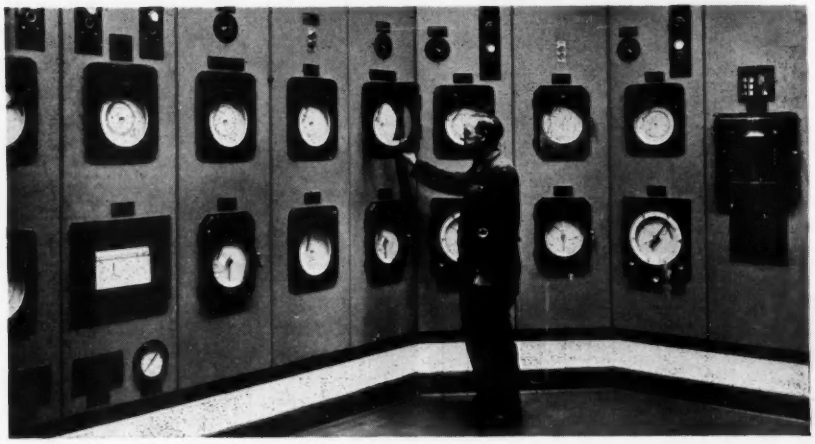


Fig. 5. A catalytic control panel illustrating multiple channel automatic control.
(*All photographs by courtesy of British Petroleum*)

The point worth mentioning is that the approach yields benefits right from the start, well before any sophisticated control equipment is introduced, and the gain is not once and for all, it is there for ever after. Automation must wait on systematisation and systematisation refines control by applying scientific methods ; the equipment merely does the job more repeatably, more accurately, and more vigilantly. In other words, a well-directed automation investigation pays and engenders an infectious fresh approach towards familiar problems.

A final thought on this aspect : once all that has been said so far has been granted, there is still a lingering remnant of scepticism, namely the prescience that a human operator is claimed to have for things going wrong before they actually do. How can automation deal with this ? Apart from the rhetorical comment that once the procedure is systematised it may not have to, there is a more direct answer to be ventured, the point of which can be gleaned by analogy.

It is surprising how much one's bank manager knows of what one is doing merely from scrutinising one's statement of account ; hardly anything of importance in one's personal life can take place without being indicated by a quantitative entry in that statement. It communicates a very real "feel" for character. Equally it is surprising how much detail of what goes on in a department can be gleaned from a single piece of paper in a well-designed budgetary accounting system ; trends, ratios and absolute values are remarkably informative.

In other words, from one piece of paper a bank manager or business manager can get quite a "feel" for what is going on. And it is suggested that this may have its counterpart in an automation control system : a selection of information received showing perhaps the trend of some overall parameters such as mass balance or heat balance, or other summary figures of operating variables, such as hourly level of fuel consumption, may do more than replace the arch-sceptic's "feel". This is the challenge to operational research, and a very appropriate area for its application.

In conclusion, one can say that the further application of what might usefully be termed automation machines must wait upon formalisation of activities. This is particularly true of industrial processes and it is not an accident therefore that there is an urgent need of suitable investigations by what may be called "automation analysts". These specialists can define the problems and sharpen the focus upon control requirements from a scientific standpoint, but the active participation of all the professionals in the specialised industries is obviously indispensable.

Measuring human stress

H. S. WOLFF

Instruments are now available for measuring several aspects of environmental stress such as temperature and pressure. But for success they must be extremely small, very light and "socially acceptable".

The term stress, when used in the definition of Young's Modulus, has a very definite meaning. It refers to the magnitude of a force which is applied to an elastic body to produce a deformation, the magnitude of the deformation being known as the strain. I intend to apply the term almost equally rigidly to the nature and magnitude of an environmental factor capable of having an action on man. In my context, it does not apply to the reaction of the biological system to the stress, which I suppose should be known as the strain, nor is it intended to have any psychological or mental connotation.

The definition requires a further possible qualification. Stress is generally regarded to be a factor disturbing some ideal equilibrium; for instance, being too hot or too cold would be regarded as stress by most people. It is, however, not out of the question that for the maintenance of health a varying environment, calling forth compensatory adjustments from the body, is a necessity and that the controlled environment imposed by modern social conditions constitutes a stress in itself.

We are therefore in the position at present of being unable to state categorically whether some deviation from comfort which is sufficiently drastic to be regarded as a stress, is bad in itself, or whether the absence of such deviations is unfavourable to man.

The similarity with the definition of Young's Modulus can be carried one stage further. If the stress applied to a piece of wire exceeds the elastic limit, then the deformation of the wire will no longer be completely reversible, and a permanent change will result. When attempting to evaluate an environment in terms of stress as applied to a man one must be careful to measure it in the right way. Three situations are possible: (i) the stress produces an effect only related to its instantaneous amplitude, and a spot measurement at the time when the information is required is all that is needed (the situation is probably rare in real life); (ii) the stress is cumulative, not necessarily for life but at least for the time of exposure. The measurement should therefore be in terms of the time integral of the magnitude of the stress; and (iii) if a threshold value of the stress is exceeded, long-term effects or damage will be caused even though the integrated "dose" of the stress may be small. This is analogous to exceeding the elastic limit on the wire.

With many common stresses it is not known whether situation (ii) or (iii) applies; in some situations both mechanisms may operate.

There is a further difficulty concerning the measurement of stress, and that is that in many cases it has not been identified. For example, it is known that some factors inherent in modern life have led to an increase in the

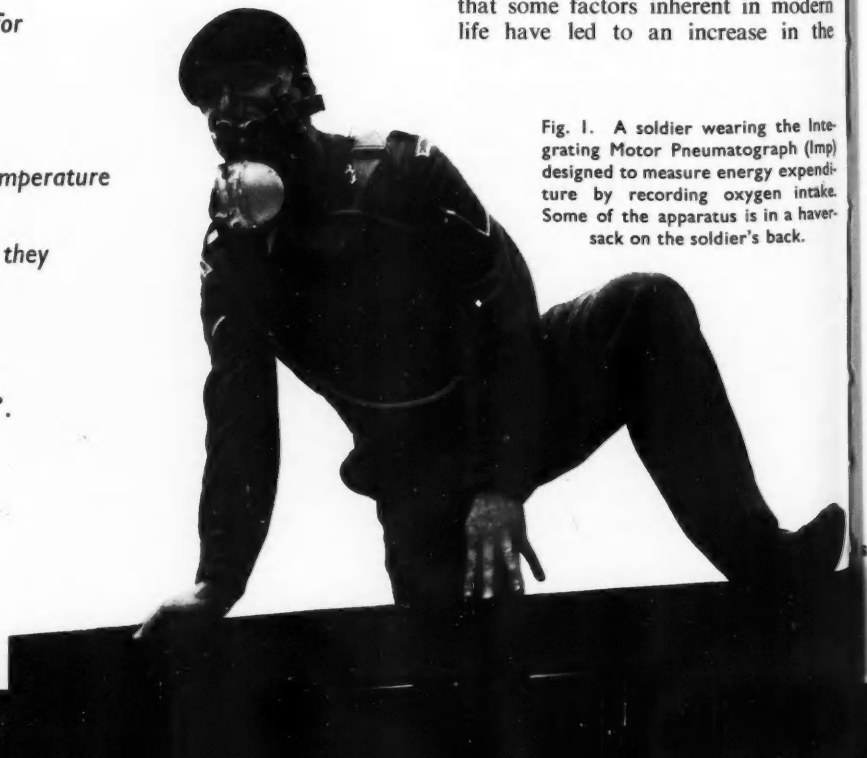


Fig. 1. A soldier wearing the Integrating Motor Pneumatograph (Imp) designed to measure energy expenditure by recording oxygen intake. Some of the apparatus is in a haversack on the soldier's back.

Fig. 2. A watch designed to record the amount of time spent by a subject below a pre-set temperature. The watch is automatically stopped when the temperature falls sufficiently and started again when the temperature rises above the pre-set value.

incidence of cardiovascular disease but the nature of these factors is not known with any certainty.

A useful approach would be to make use of the known differences in incidence among different sections of the population, or in different countries, and to correlate these with long-term measurements of environmental factors, nutrition and physiological variables. Heart rate, blood pressure, respiration rate and volume would be examples of the latter.

This requires an invasion into the normal lives of a statistically significant number of normal people, with measuring instruments which should essentially be carried on the person. Programmes of work are just beginning to provide such instrumentation, which, in addition to satisfying the criteria of measurement, has to have sufficient social acceptability to make large scale experimentation possible. The instruments which I shall describe are the ancestors of such a future range of devices. They were designed to measure environmental or physiological variables in situations where social acceptability was not important, and where the size and weight of the instrument, within limits, could be compensated for by removing some other load from the experimental subjects. A typical example would be a soldier carrying a 6 lb. recorder in his pack from which a pair of boots had previously been removed.

The approach is parochial in as far as the instruments have been chosen from those developed in my laboratory, but they will serve to illustrate general principles.

The temperature-sensitive watch

In an attempt to study the reaction of man to cold stress in terms of cold acclimatisation, a simple instrument was required to measure the time which a given individual spent below a set environmental temperature. The device had to be cheap enough to be produced in some quantity and to require no maintenance. Fig. 2 illustrates the original solution. The instrument consists of a good quality pocket watch which has been modified by soldering a brass boss to the case adjacent to the balance wheel. The boss carries the stem of a bimetallic thermometer. A shaft protrudes from the top of the stem inside the watch. The shaft, which rotates as the temperature changes, carries a small lever, which when it reaches a certain position, mechanically interferes with the balance wheel and stops the watch. The setting accuracy is about $\pm 1°C$. In use, the watches are all set to the correct time and examined 24 hours later. The amount of time by which a watch is slow is equal to the time of exposure below the set temperature.

The present instrument has some disadvantages; the mass of metal is relatively large so that the response time can be of the order of minutes, introducing errors when changes from indoors to outdoors are frequent. It is also too conspicuous to be socially acceptable in populations less highly selected than the Antarctic expeditions on which this work was done.

An electric version is now being developed in which a very small battery driven electric clock is stopped and started by a temperature-sensitive switch not much bigger than a tie-pin. The clock can be in a pocket, the sensing device being pinned to a lapel. The device can, of course, equally well be used to measure heat stress, and more than one can be worn if discrimination between two or more temperature levels is required.

The miniature recorder

This instrument was designed to make recordings on a chart of the time course of any environmental or physiological variable which could be converted by means of a suitable transducer into a small voltage, a change in voltage, or a change in resistance. Fig. 3 shows the recorder with its battery power supply sufficient for 100 hours, and with the chart clock removed to show the circular chart.

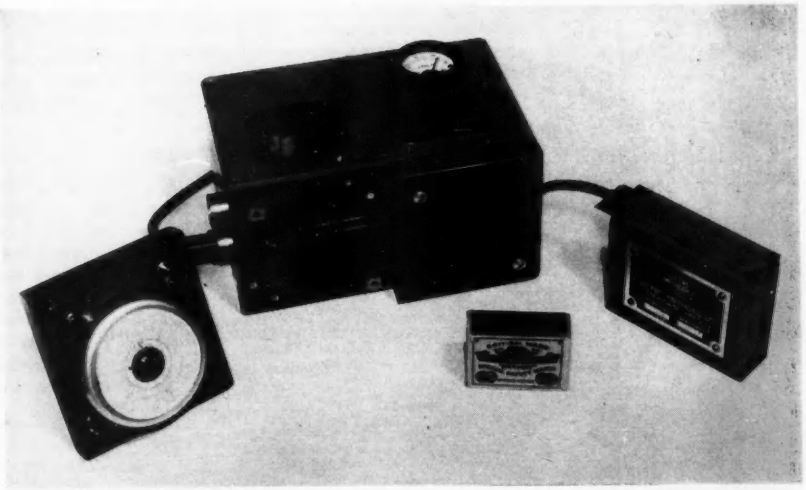


Fig. 3. A miniature recorder that will chart any physiological or environmental variable that can be converted into a small electrical change. It can be used, for example, with the wire suit (see Fig. 4).

Interchangeable clocks will rotate the chart at times varying from 1 hour to 6 days. The paper is basically black with a coating of white wax which is scratched away by a hard metal stylus moved by the pen motor. The line is sufficiently thin to allow a resolution of 1% of the chart width.

When working with transducers which change their resistance, the recorder is connected as a self-balancing Wheatstone bridge. The transducer forms one arm of the bridge, and plug-in resistors and a servo-motor driven variable resistance form the other arms. The error signal from the bridge is amplified and applied to the servo-motor in the appropriate sense so as to move the variable resistance in the direction of bridge balance, so cancelling out the error. The servo-motor also drives a leadscrew along which the stylus travels so that the variations in transducer resistance are reproduced on the chart. To compensate for any drift in the amplifier the chart clockwork motor momentarily closes a pair of contacts every 6 minutes, which remove the error input from the amplifier and connects the output to a second servo-motor which drives a rebalancing control in the amplifier circuit.

The recorder will operate at ambient temperatures between −20°C and +50°C provided that the power supply is kept above 0°C. It is for this reason that it has been separated from the recorder proper so that it can be slipped underneath the clothing close to the skin and kept warm. The total weight is 6 lb., which is acceptable for investigations on experimental personnel but too large for unmotivated subjects.

One of the first transducers used with the miniature recorder was the wire suit.

The wire suit

One of the possible effects of cold acclimatisation might be that the acclimatised subject is prepared to tolerate without complaint a lower skin temperature than the unacclimatised subject. To investigate this effect a knowledge is required of the mean skin temperature over as much of the body surface as possible. Conventionally this measurement is made by attaching a number of thermocouples to the skin at selected sites and to weight the individual readings with a factor proportional to the area which a particular thermocouple is supposed to represent, before calculating a mean. The wire suit *(see Fig. 4)* avoids this procedure by covering most of the body surface with an evenly distributed resistance thermometer. This is achieved by knitting a complete set of underwear from a continuous length of very flexible multistranded copper wire. Copper has a temperature coefficient of resistivity of about 0·4%/°C so that the resistance of a pair of 50 ohm underpants might change by 0·2 ohms/°C. The suit actually shown in Fig. 4 is an improved version in which both wire and terylene thread are used to increase its resistance to wear.

Fig. 4. A suit knitted from flexible copper wire and terylene thread designed to measure the mean skin temperature over a maximum area of the body surface.

The results of the work showed that there was no shift in the comfort range of skin temperatures in personnel who had been in the Antarctic for one year as compared with new arrivals. This does not mean, of course, that there is no cold acclimatisation but only that either acclimatisation does not manifest itself in this way, or that modern clothing and housing are sufficient to remove any cold stress from the individual and that thus no adaptation is elicited.

The instruments described so far have all measured stress as initially defined. There are situations, however, where the measurement of the stress becomes very difficult and where the biological effect, the strain, has to be used as an index of the stress.

The measurement of how hard people work is one such case. In normal life it would be very difficult to estimate the work content of each action, but it is relatively easy to express an hour's or a day's work, or even a rate of working, in terms of fuel

Fig. 5. The Integrating Motor Pneumatograph. (F) : a flowmeter which records the output as a small voltage. (B) : a very low friction electric motor that integrates the flowmeter voltage with respect to time. (C) : a container for the expired air that will later be analysed.

consumption of the man. The Integrating Motor Pneumatograph (Imp) *(see Fig. 5)* is one instrument intended to measure the energy expenditure under near normal conditions. Fortunately, a close relationship has been shown to exist between fuel consumption and oxygen consumption. It is therefore only necessary to measure the amount of oxygen abstracted by the body from the inspired air to be able to calculate energy expenditure.

The Integrating Motor Pneumatograph (Imp)

The subject wears a rubber mask fitted with three inlet valves and a flowmeter, F, through which the expired air passes. The flowmeter gives an electrical output (volts) proportional to the rate of flow through it. This voltage is integrated with respect to time by a very low friction electric motor contained in the unit B. This motor drives a cyclometer counter which indicates the volume which has passed through the flowmeter. The unit B also contains a single stroke pump which is actuated every so many litres and snatches a small volume through a tube from the flowmeter and pumps it into a butyl rubber bag contained in the aluminium canister, C. At the end of a period of measurement three items of information are available: (i) the composition of the inspired air (usually regarded as constant all over the world); (ii) the volume of expired air; and (iii) by analysis of the sample stored in C, the composition of the expired air. The amount of oxygen used can therefore by calculated and hence the energy expenditure.

The Imp, which has been widely used in investigations on service men *(see Fig. 1)*, is a crass example of an instrument of low social acceptability, largely because of its mask. There appears to be no satisfactory way at present of measuring either energy expenditure or ventilation rate by mask-less methods, which are applicable to normal life. This is the more unfortunate because both these factors are likely to play an important part in the estimation of some stresses. The only hope at present is to develop methods based on chest expansion and movement of the chest wall.

When a subject is likely to operate within a restricted area, or when loading in terms of instruments must be kept to an absolute minimum, it is possible to use very small radio transmitters to transmit data from the subject to a remote receiver. Fig. 6 illustrates a telemetering transmitter which under favourable conditions in the open can have a range of several hundred yards. The design is such that it can be frequency modulated adequately by input voltages of less than 1 mv. This makes the transmitter directly applicable to the transmission of the electro-cardiogram without any amplification between the electrodes and the input. Electrodes based on 1 inch circular adhesive dressings, incorporating a circle of silver foil and some conducting jelly, can be worn without discomfort for several days. Heart rate, which again should be regarded as a measure of strain rather than stress, could thus be monitored over long periods.

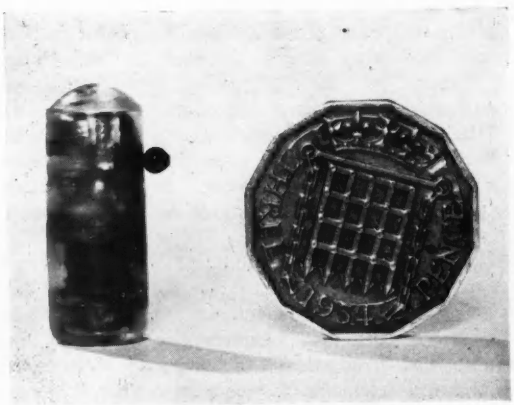
Telemetering techniques are useful for investigations concerned with sport and other occasions when the subject can be kept within range. When this is not the case recordings have to be made on the subject.

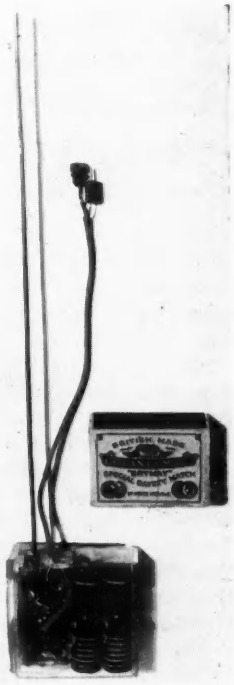
Present work includes the design of very small recording systems, the size of a paperback book, for a four-channel recorder. Miniaturisation techniques of high order will have to be employed on the transducer side as well. What can be done in this way is shown by the development in a number of centres of complete transducer/radio-transmitter systems colloquially known as radio pills (Fig. 7) small enough to be swallowed. These can be made to transmit data on temperature, pressure and pH from the gastro-intestinal tract, and will, in time, take their place in the investigations of the stress/strain relationship leading to duodenal ulcers and allied conditions.

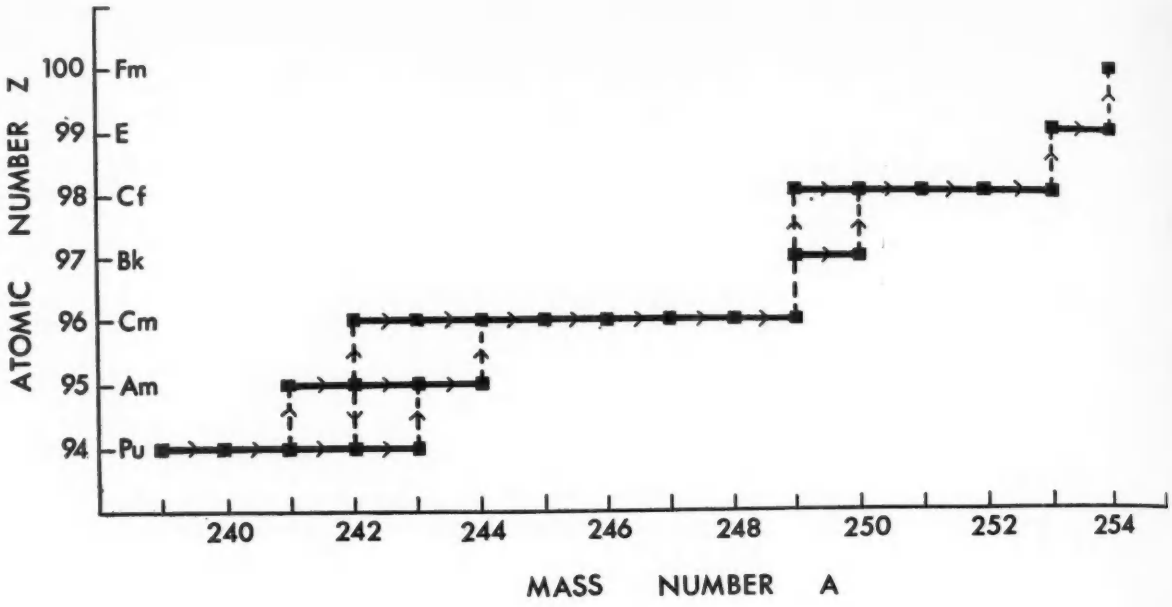
There is no doubt that with modern instrumentation techniques the measurement of almost every conceivable variable becomes possible, and only technical problems have to be overcome but it is a far greater problem to decide what to measure and how to unravel the interaction of different stresses.

Fig. 6. *(Right)* A telemetering transmitter used to relay data when the subject must be kept as free from instruments as possible. It may be used, for example, to transmit information concerning the heart.

Fig. 7. *(Below)* The radio pill—a complete transducer/radio transmitter system which, when swallowed, will transmit data on pressure from the gastro-intestinal tract. Other models can transmit information concerning pH and temperature.







The search for new elements

ALBERT GHIORSO

The 103rd element, recently made in the laboratory by the author, is the last of the actinides. It required techniques far in advance of those needed to produce the other man-made elements. How many more new elements can be made?

The old dream of the alchemists, the creation of new elements out of old, continues to be transformed into reality. Recently the 103rd element was identified at Berkeley and thus became the fourteenth of the so-called man-made elements. However, as will be shown in this article, we are rapidly exhausting the possible methods of manufacture so that even with the tremendous scientific capabilities of this modern world it is doubtful that the number of elements can be extended beyond about No. 107.

The discovery of lawrencium, the 103rd element, was the culmination of almost three years of research and involved the invention and development of many techniques before success was finally attained. A description of the difficulties encountered and how they were overcome in this experiment should serve to illustrate the problems in extending the Mendeleev table of elements beyond uranium, the 92nd and heaviest of the natural elements.

Up to element No. 100, fermium, it is possible to manufacture relatively long-lived isotopes of all the trans-uranium elements by suitably long irradiations of uranium or heavier elements by neutrons. This is accomplished in the great chain-reacting neutron-producing assemblies called reactors. In this process (*see Fig. 1*) the starting material captures slowed-down neutrons successively until a nucleus is made that decays by beta particle emission to the next higher element. This nucleus in turn captures neutrons and the process is repeated. Using this method, a national programme now under way in the United States will produce kilogram amounts of americium and curium, milligram amounts of berkelium and californium, microgram amounts of einsteinium, and nanogram (10^{-9} gm.) amounts of fermium.

Beyond element 100 this process cannot be used, for at 100 a condition is reached where the nuclei decay by alpha particle emission or by spontaneous fission as fast as they are produced. One method of going beyond this barrier is to make use of an intense fast neutron device—for example, a modified thermo-nuclear weapon exploded in a confined space. This relatively large and expensive undertaking has been proposed but

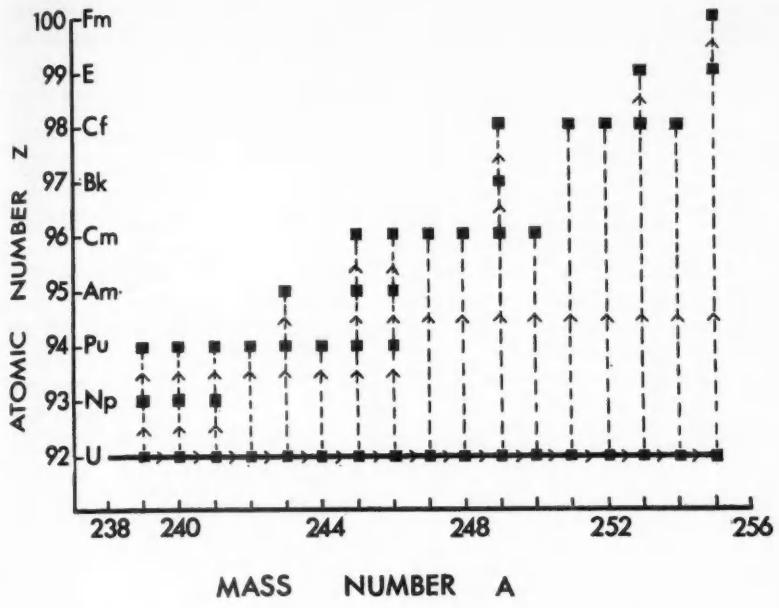


Fig. 1 (*Left*) The ways in which elements up to No. 100 can be made. A heavy element is bombarded with neutrons causing neutron absorption (heavy horizontal lines) until a point is reached where β particle emission—either positive or negative—occurs (vertical dotted lines).

Fig. 2 (*Above*) Elements formed in the U.S. thermo-nuclear explosion in 1952. The continuous horizontal line represents neutron capture and the broken line represents β decay.

not yet attempted. A somewhat accidental by-product of the U.S. 1952 thermonuclear test was the discovery of elements 99 and 100 produced in this manner (as many as 17 neutrons were captured in a matter of microseconds) but only an infinitesimal amount of the reacting material was recovered from local fall-out. Any attempt to retain a large percentage of the intensely radioactive contents of such an explosion and to mine it quickly for transfermium elements is obviously fraught with tremendous difficulties. It is by no means even certain that any transfermium nuclei that can be made in this manner would have half-lives long enough for them to survive the necessary chemical processing. The sequence of nuclear transformations obtainable in this way is shown in Fig. 2.

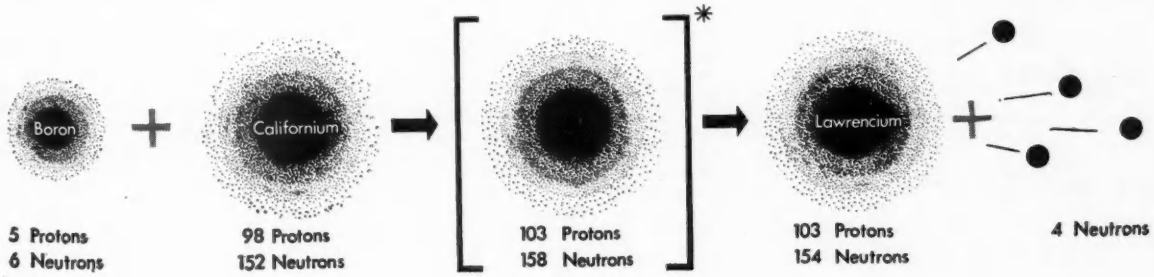
Methods for producing element 103

The other method of surmounting the fermium barrier is to make use of fast particles containing from one to more than ten protons. When accelerated to energies in Mev (million electron volts) of more than about five times the mass of the particle, the particle can overcome the charge repulsion of the bombarded nucleus and a nuclear reaction can take place. For example, the bombardment of element 98, californium, with element 5, boron, produces the newest element, 103, lawrencium. One of the nuclear reactions ultimately observed is shown in Fig. 3.

The transitory stage of the reaction represented by the starred brackets in this diagram indicates only a momentary state excited by the amalgamation of a boron with a californium nucleus. Under the most favourable conditions the change of this compound nucleus into a lawrencium nucleus resulted only once in a hundred thousand times that a nuclear reaction took place. The end result of the amalgamation 99% of the time was a fission into two lighter elements. One per cent of the cases resulted in the ejection of alpha particles and neutrons to make nucleii with an atomic number of 100 or less. To make the problem yet more difficult, the conditions of the experiment were such that only one out of about 10^{11} of the impinging boron ions could penetrate the californium nuclei to produce a nuclear reaction at all.

The difficulties encountered at Berkeley early in 1958 in identifying element 102 by a somewhat similar heavy ion reaction led us to predict that the production of element 103 would be even more of a problem. The amount of californium available for a target was orders of magnitude less than the curium target material used in the 102 experiments. This

Fig. 3 When californium is bombarded with a boron nucleus an intermediate is formed that immediately breaks down to give lawrencium and four neutrons. This reaction is typical of those used to produce the man-made elements. *Indicates the unstable intermediate compound.



Period	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8		
1	1 H									2 He
2	3 Li	4 Be	5 B	6 C	7 N	8 O	9 F			10 Ne
3	11 Na	12 Mg	13 Al	14 Si	15 P	16 S	17 Cl			18 A
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni
	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br			36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd
	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I			54 Xe
6	55 Cs	56 Ba	57-71 Rare Earths	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt
	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At			86 Rn
7	87 Fr	88 Ra	89-103 Actinides *	(104)	(105)	(106)	(107)	(108)	(109)	(110)

*

89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 E	100 Fm	101 Mv	102 No	103 Lw

The Periodic Table : the first 92 elements occur naturally and those heavier than uranium have been manufactured in the laboratory. The actinides, of which lawrencium (No. 103) is the last member, are shown shaded.

NUCLEAR TRANSMUTATIONS

Every nucleus is defined by its atomic number (Z) and its mass number (A).

The atomic number gives the number of protons in the nucleus, and so defines which element it is. Thus all uranium nuclei (Z=92) have 92 protons.

The mass number gives the total number of protons plus neutrons in the nucleus. Thus U^{238} (92 protons plus 146 neutrons), U^{235} (92 protons plus 143 neutrons).

Nuclei can change, or be changed into others, in the following ways :

Neutron capture	**Raises mass number by 1.**	$_{94}Pu^{239} + n = {}_{94}Pu^{240}$
Heavy ion capture	**Raises mass and atomic numbers by those of the captured ion.**	$_{98}Cf^{250} + {}_{5}Be^{11} = {}_{103}La^{261}$
Alpha decay	**The nucleus throws out an alpha particle (that is, a helium nucleus) consisting of 2 protons and 2 neutrons. Lowers atomic number by 2 and mass number by 4.**	$_{92}U^{238} - \alpha = {}_{90}Th^{234}$
Beta decay	**The nucleus throws out an electron (either positive or negative). No alteration to mass number, since the electron mass is insignificant. If a negative electron is emitted, the nucleus gains a positive charge (that is, a neutron becomes a proton) so the atomic number is raised by 1. Similarly, the loss of a positive electron lowers the atomic number by 1.**	$_{90}Th^{234} - \beta^{-} = {}_{91}Pa^{234}$

difficulty could be partially overcome by concentrating the californium into a much smaller area and passing all of the beam of boron ions through it to increase the probability of a reaction. This immediately posed two severe problems: concentrating the target and focusing down the heavy ion beam.

The heavy ion source

The machine used at Berkeley for accelerating heavy ions is a large linear accelerator (HILAC) that was completed in 1957 (*see Figs. 4 and 5*). Heavy ions are accelerated in this device in three distinct steps. The ions are created by striking an arc in a gas at low pressure in a magnetic field. For boron the gas used is BF_3, which is highly corrosive when in contact with moisture. The abundant B^{+2} ions (i.e., boron atoms with two electrons missing) are extracted electrically from the arc and accelerated through a vacuum column across which about 500 kV is maintained by a Cockroft-Walton type power supply. These ions are then injected into a 10 foot long section of linear accelerator operating at 70 Mc/s. After passage through this pre-stripper cavity the ions now have an energy equal to 1 Mev times their mass number. The ions then coast through about a centimetre of mercury vapour curtain (a few micrograms per cm^2 thickness) and after emergence through this stripper about one half of them have been stripped of all but one electron to make B^{+4} ions. These are then accelerated in the post-stripper tank.

This 100 foot long cavity also operates at 70 Mc/s and contains 67 drift tubes through which the accelerating particles must travel. Strong magnetic lenses "squeeze" the beam so that more than half of the beam entering the post-stripper emerges at the far end concentrated in a cross-section of less than 10 $mm.^2$ and with an energy in Mev of 10 times the mass number of the ion being accelerated. Initially the beam current that we were able to obtain was only 0.05 microamperes but with modifications and careful tuning this current was eventually increased by more than an order of magnitude ; in fact, in the later experiments it was necessary to limit the beam delivered through the californium target to 0.5 microamperes to reduce the risk that its backing nickel foil would be melted.

The californium target

The target itself presented another crucial problem. For one thing, it had to be concentrated into a tenth of an inch diameter area. Also, it was found in the earliest experiments that tiny amounts of lead and/or bismuth impurities left in the target or its mounting foil would produce an alpha particle activity with characteristics very similar to those that we were predicting for an isotope of element 103. This activity turned out to be coming from a known isomer of polonium—Po^{211}. The only solution was to rid the target and its environment completely of lead and bismuth, but a year passed before a satisfactory approach was obtained.

The methods we finally adopted successfully were the following. The thin, 30 micro-inch nickel foil upon which the californium was to be electroplated was first heated in vacuum to about 1,000°C for several minutes to volatilise out the impurities. The californium was then electrodeposited in a cell specially designed to give a high yield. The resulting somewhat flaky californium hydroxide deposit was then treated for a short time with HF and HCl vapours to convert the californium to an oxyfluoride and the lead and bismuth to oxychlorides. The target was then heated by electron bombardment at 1,000°C for several minutes. The net result was beneficial

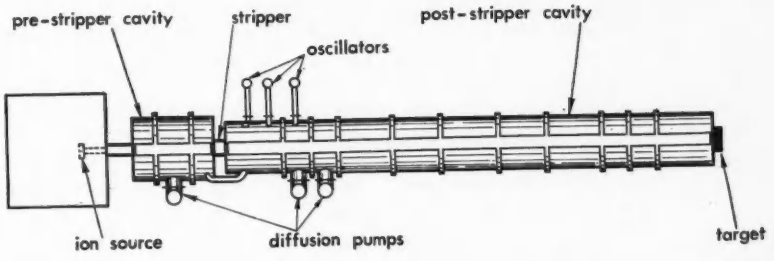


Fig. 4 (*Above*) Part of the HILAC (heavy ion linear accelerator) used for the production of the 103rd element, lawrencium. The photograph shows the post-stripper cavity, over 90 feet long.

Fig. 5 (*Below*) Boron ions are accelerated in the pre-stripper cavity of HILAC. When they reach the stripper—a curtain of mercury vapour—further ionisation occurs forming B^{+4} ions. These are then accelerated in the post-stripper cavity and travel on to the californium target.

in two ways : first, the few micrograms of californium were converted into a very stable adherent coating on the nickel foil, and second, the remaining lead and bismuth impurities were largely vaporised away. Only a negligible fraction of the californium was lost in these processes.

Detecting the new element

Having set up the target and the bombarding ion beam, how could we detect the existence of the atoms of 103 that were to be made ? From the very start of the search for this elusive element it was known that we would be looking for an atom that would decay with a short half-life by emitting alpha particles in the range between 8.5 and 9.0 Mev. This could be reliably predicted because during the preceding 15 years the general trends in the ways that alpha energies and half-lives varied with atomic and mass numbers had been carefully studied and had given rise to a whole new field called by the general name of alpha radioactivity systematics (*see Fig. 6*).

In the case of an element with an odd atomic number there is a greater range in the predicted values for the half-lives of its isotopes, so our predictions for the possible element 103 isotopes indicated that we should search for activities in the range from a fraction of a second to as much as a minute.

The first experiments designed to uncover an isotope of the unknown element were based on the assumptions that the production cross-section (or probability) and half-life were both larger than normally expected. To secure an immediate fast separation of any new atoms from the highly radioactive target, advantage was taken of the fact that when the atom is formed it is ejected from the target with the substantial momentum transferred from the amalgamating heavy ion. The transmuted atoms were caught in a thin palladium leaf foil and after a few minutes this bombardment was removed from the target chamber for further treatment. The range of the recoiling atoms is considerable so that they embed themselves deeply in the palladium foil. As a result the alpha particles from their subsequent decay suffer a substantial loss of energy which varies for each with the angle at which

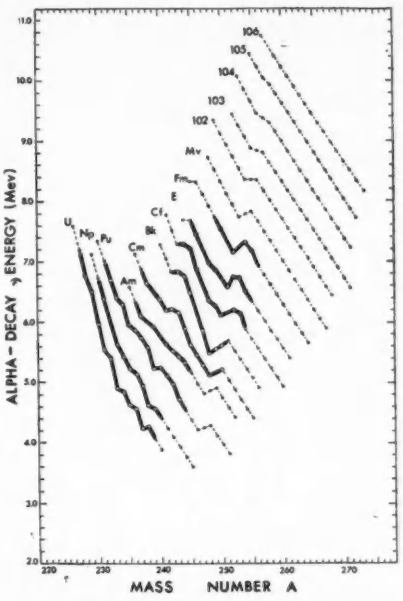


Fig. 6 Alpha-decay energies for the isotopes of the transuranic elements plotted against their mass number. In order to be able to detect lawrencium it was vital to know its α-decay energy. The continuous lines represent portions on the graph where the values have been obtained by experiment or calculation; the dotted lines represent estimated values.

it emerges from the foil. Direct measurement of these alpha particles discloses a broad spectrum of energies and is thus almost impossible to interpret if other alpha activities are present. To obtain a thin sample for alpha particle analysis quickly the palladium foil was dissolved and the solution eluted in an ion exchange resin column. Under the proper conditions it is possible to separate quickly from the column a fraction containing all the elements between 95 and 103, inclusive. Experiments of this nature were performed at various B^{11} bombarding energies and careful analysis showed the known nuclei Fm^{253}, Fm^{254}, Fm^{255}, Fm^{256}, E^{253} and E^{254} to be prominent but no new alpha activities of Mv, of 102, or of 103.

The next step was to look for very short-lived alpha-emitting atoms. The instrument that had been used for alpha particle analysis until the advent of the solid state detectors in 1960 was the famous Frisch grid chamber. This device measured the amount of gaseous ionisation caused by the passage of an alpha particle by screening out the fast moving electrons from the positive ions with an appropriately biased grid in a parallel plate ionisation chamber.

In order to use such a Frisch grid chamber near the target many modifications had to be made to the normal operating conditions to enable the system to withstand the large ionisation from induced radioactivity caused by the beam. In addition, since the HILAC beam is emitted 15 times per second in pulses 2 milliseconds long, the detector system had to be shut off for a few milliseconds during each beam burst to prevent the momentary ionisation from overloading the equipment. This would happen even though several inches of lead shielding were interposed between the place where the atoms were collected and the position where they were analysed.

To transport the atoms to the grid chamber a novel method was arranged. In the target chamber the transmuted atoms were stopped in a helium atmosphere ; since they were still ionised they could then be attracted electrically to the aluminium coating on a mylar plastic tape which was used as a conveyor belt. At the end of a suitable bombardment period the tape was pulled swiftly a distance of about 5 inches into the argon-CO_2 filled ion chamber directly below for analysis and while this analysis was proceeding the next collection was being made.

In this way many separate short bombardments could be carried out and their results combined, for in addition to detecting the individual alpha particle decays, the times when they occurred were recorded automatically. Thus the half-lives and energies for short-lived alpha activities could be readily measured, and within the limitations imposed by the method good results were obtained.

Experiments aimed at finding an isotope of element 103 which made use of this grid chamber system were unsuccessful for two main reasons. First, the amount of californium available for a target was much too little—only about 0.2 microgram of the element —and secondly, the lead-bismuth impurity problem had not yet been solved. Several times we thought that we had detected the elusive 103 only to find that rigorous tests proved that our unknown activity was produced from

one or both of the impurities. However the HILAC operation was continually refined and improved until it finally became almost routine to obtain 0.5 microamperes of beam current through the small target. Bombardments with this beam of various other targets to produce known and unknown heavy nuclei gave cross-section data that soon made it possible to calculate quantitatively the way in which the reactions to produce element 103 would vary with bombarding energy. The chief weak point of the method was the poor resolution of the ion chamber imposed by the intense radiation.

Improved detectors

The solution of this difficulty was soon at hand with the demonstration at Oak Ridge National Laboratory and other places of the excellent abilities of semi-conductor detecting devices for charged particle analysis. The development of solid-state particle detectors was a logical outcome of the tremendous growth of transistor technology but the fact that useful devices would become readily available so quickly caught most physicists and chemists completely by surprise.

The type that was to become most used was the gold-silicon surface barrier device. This consisted of a thin wafer crystal of high purity n-type silicon with an ohmic connexion on one side and on its other carefully etched side another connexion through a very thin evaporated gold layer.

These new alpha particle analysing detectors had many advantages when used in our apparatus in place of the grid chamber : (1) the area of one of these crystals was about one hundredth that of the ion chamber so that the intercepted radiation from the HILAC beam was no longer a problem ; (2) the effect of the beta radiating activities picked up on the tape transport was reduced because faster amplifiers could be used ; (3) the small size meant that the detector could be moved closer to the target and so ease the requirements for the tape-pulling mechanism ; (4) instead of only one detector five detectors were installed so that the activities could be analysed five times as long as the bombardment times and so cover a wider range of half-life ; (5) the tiny area of the device meant that its background was negligible ; and (6) the counting gas was dispensed with leaving only the helium in the target chamber.

The disadvantages that had to be overcome were mechanical and electrical. The small size meant that the ions had to be collected in a small area and that the tape pull had to be precise and constant to reach the centre of the fifth detector with the packets of collected atoms effectively. The five-fold increase in number of amplifiers and the need to store five times as much information increased the electronic complexity tremendously but the extra data obtained made this extremely worthwhile.

The solution of these problems took some months of careful design and test but finally a radical but reliable system was evolved (*see Fig.* 7). The transmuted atoms which recoil out of the target are carried through a small hole at the bottom of this chamber by a gently flowing stream of helium as either positive or negative ions. The exact mechanism that takes place here is not yet understood but suffice to say that collection efficiencies between 50% and 100% are usually secured. After leaving the target chamber the ions (usually negative) are attracted to the copper or aluminium conveyor belt on to an area of a few square millimetres. When the belt is moved to a position next to a crystal detector a resolution of about 40 Kev is usually obtained.

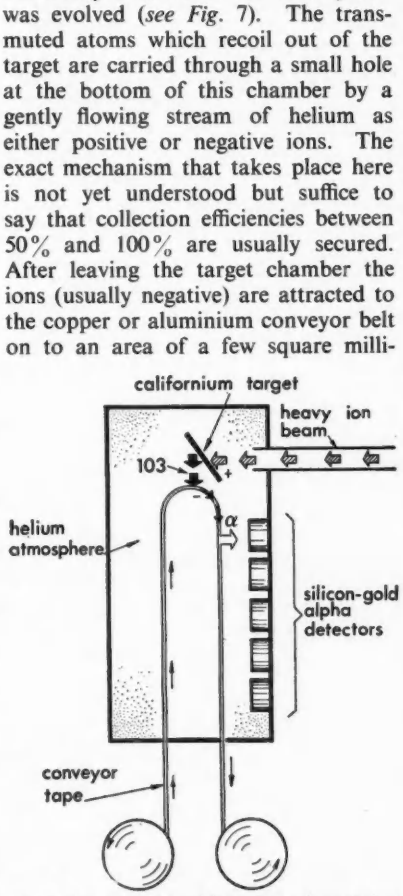


Fig. 7 In order to be able to detect lawrencium when it had been produced, the transmuted atoms were electrically attracted to a movable plastic tape. This conveyed the atoms to specially made silicon-gold detectors that could analyse their α-energy decay.

Finally, the equipment was working satisfactorily as demonstrated by its ability to find a new short-lived isotope of einsteinium, E^{245}. Crucially important, a larger new supply of californium was now available. The methods outlined earlier had been successful in the preparation of a very pure target containing about three micrograms of the element.

The final experiments

The initial experiments were designed to find an isotope of element 103 with a half-life in the 5 to 50 second region and were immediately successful. A few alpha decays were observed with an energy of about 8.6 Mev and it was felt that these would turn out to be due to the long sought after 103rd element. First preliminary data indicated a half-life of roughly 15 seconds for these alpha particles with a similar half-life group, but more abundant, at 8.2 Mev. Every effort was now made to untangle the evidence, only to come up against new difficulties. Apparently a new source of spurious electrical background had been uncovered ; the very few alpha particle events observed per hour became masked and in addition the yield of these events seemed to vary erratically.

In our earlier work we had shown that the boron-californium reaction which we were using to make this element would be characterised by a sharp excitation function, i.e., a yield sharply varying with bombarding boron energy. It had been hoped that this function would provide the final proof that the new activity was due to 103. After the initial difficulties were cleared up it was apparent that the maximum amount of activity that we would make of the 8.6 Mev alphas (now found to have an 8 second half-life) was only 5 or 6 counts per hour. This was enough, though, and on February 14, 1961, a long set of experiments provided enough good evidence to convince us that we had found element 103.

Final proof

This was an exciting result but we had to be cautious and obtain undeniable proof ; this was to be the first

time that a new element was discovered without assistance of chemical methods. The excitation function was disappointing in its ability to distinguish the particular reaction involved because the presence of the three prominent isotopes in the target, Cf^{250}, Cf^{251} and Cf^{252}, meant that the same isotope of 103 could be produced by three different reactions which peaked over a wide range of energies. We then turned to another powerful method which had been used for years to distinguish new isotopes of the known elements—the method of cross-bombardments. By arranging to make the same nuclei in a number of different ways, for example, by changing the target and projectile, it is possible to narrow down the possibilities as to its origin.

In this case we were certain that the 8.6 Mev activity could only be due to Mv, 102, or 103, on the basis of previous experiments with boron bombardments of Pu^{239}, Pu^{240} and Np^{237}. We knew that if we bombarded the Cf target with C^{12} ions we would accentuate the production of element 102 and reduce the amount of 103 when compared with the boron runs. This was done with the gratifying result that the 8 second 8.6 Mev peak decreased and the 15 second 8.2 Mev peak increased. This strongly indicated that the latter activity was due to element 102, probably 102^{255}, and the former to 103. Mv was ruled out by bombarding Am^{243} with C^{12} ions to show that the 8 second activity could not be produced.

The data was now consistent and conclusive that element 103 had indeed been found. It indicated that the mass number of the isotope was probably 257, the heaviest atom ever detected on earth. In memory of the great pioneer of accelerators, Ernest O. Lawrence, element 103 was named lawrencium.

How many more elements?

Soon there will be available in our laboratory an order of magnitude more berkelium and californium. With these as target materials we will be able to identify other isotopes of element 102 and lawrencium by using boron, carbon and possibly beryllium ions. It should also be possible to determine in some cases their mass numbers by identification of their daughter decay products. This will be done by the use of sophisticated techniques in which advantage is taken of the recoil imparted by alpha decay of the mother atom. The re-naming of element 102 by its Berkeley discoverers will thus await this final definitive test of the validity of the 1957 claim to existence of a 10 minute 8.5 Mev isotope of the element.

Some thought has already been given to the possibility of finding an isotope of element 104 through the use of this larger amount of californium. It appears that by using C^{13} ions the cross-section for the reaction might be almost as large as the (B^{11}, Xn) cross-sections. A difficulty might be that the 104 half-lives will be too short for the present tape transport system. In that case we have plans to modify the method and use electrical focusing to attract the transmuted charged atoms to a crystal detector.

Instead of analysing the primary activities, the daughter atoms which recoil from the drum will be examined in sectors by suitably placed detectors which will attract the charged alpha decay products. When properly tested and perfected this method promises to be a powerful tool for this work.

The two important obstacles to overcome in making even heavier elements are production cross-section and half-life. The heaviest target that can be visualised in microgram amounts is the long-lived isomer of E^{254}. To make element 105 thus requires the capture by bombardment of at least six protons—that is, at least a carbon ion. The cross-section for the likely reactions is probably less than one microbarn. Elements 106 and 107 would need nitrogen and oxygen ions impinging on this target and their cross-sections would be smaller by one and two orders of magnitude. The half-lives of the isotopes that could be made by these processes will become progressively shorter for two reasons. Their alpha decay is certain to become accelerated and decay by spontaneous fission is likely to become even more prominent. The net result is to make it very difficult to produce and identify elements with greater atomic number but the thought that these estimations may prove wrong is always an incentive to make the effort worthwhile. The tantalising possibility that has long occurred to several scientists that a new relatively stable region might appear in the heaviest elements cannot be denied.

One of the very interesting experiments that must somehow be performed is to show that element 103 is the last of the actinide elements, a series analogous to the rare earth elements in the middle of the periodic table. The longest-lived isotope of lawrencium may not have a half-life of more than a minute or two and this will make it difficult to use ion-exchange elution column techniques. Element 104 will almost surely not have isotopes with half-lives beyond the seconds region so that conventional chemical methods will be impossible. One possibility would be to use volatility as a means of separation of 103 and 104. Lawrencium should be very volatile, while 104, being a chemical homologue of hafnium, should be relatively non-volatile. Other possible methods might make use of gas flow reactions, migration of gaseous atoms or ions, or surface reactions. It is evident that much ingenuity is called for.

One might ask where the greatest value of this field of research lies. At the present time this is a difficult question to answer firmly. Many new experimental techniques have arisen from or been stimulated by this work which have proved valuable to a whole area of science. Certainly the very important field of nuclear decay systematics has been much stimulated by the new alpha decay information derived from the heaviest elements. For example, a minor stability sub-shell at 152 neutrons has been found with the discovery of einsteinium and fermium which promises eventually to throw more light on nuclear configurations. Spontaneous fission has emerged as a very important tool in the laboratory study of nuclear fission now that the isotope Cf^{252} is readily available. In addition to these advances in the field of pure research there must be included those practical applications that are gradually being discovered for the heavy elements—for example, the use of Pu^{238} or Cm^{242} for the production of power in space vehicles. Perhaps the most important reason for pursuing the search for more elements is simply to satisfy man's curiosity as to what is beyond the next turn.

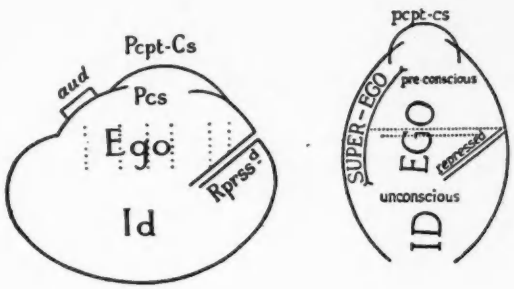


Fig. 1. Sigmund Freud (*left*) saw the personality as a three-layered structure consisting of the ego, superego, and id. It was the mutual relation of these three realms which most concerned him. The diagram on the left dates from 1923; the one on the right was made a decade later. Both present the mental apparatus as though spatially stratified. Modern Freudian theory has gone a long way towards mapping the relationships symbolised in the diagrams.

In defence of Freud

J. A. C. BROWN

Psychoanalysis or behaviour therapy—which is the more effective method for treating neurosis? Recently the followers of Freud have been strongly challenged by the behaviour school, based on Pavlov. In this article a psychoanalyst answers the attack.

In April of this year Professor Eysenck published an article in DISCOVERY describing a new method of treating neurosis known as "behaviour therapy" based on Pavlov's concept of the conditioned reflex. This he believes to be "almost certainly on the right lines (although) at present no more than a theory in the process of being evaluated." By contrast, he attacked Freudian theory as being not only wrong but actually guilty of retarding progress in the psychological field very seriously.

Obviously psychoanalysis is a hypothesis—as he has for long made evident—upon the erroneous nature of which Eysenck has no reservations whatever. It follows that any defence of the Freudian position must not only be prepared to give some good reasons for supporting this particular viewpoint; it must also attempt to show that the contrary approach from which behaviour theory derives its rationale is, if not wholly wrong, at least inadequate to explain the observed facts.

However, the first of these tasks is much more difficult than the second. Not only did Freud put forward a whole series of hypotheses, discarding in the later ones some of the views he had held earlier, but his followers have added considerable modifications. Psychoanalysis is no longer a single theory but a whole branch of applied psychology, comparable to industrial or social psychology. Thus, while it is possible to summarise Pavlov's concept of the conditioned reflex in a dozen lines, it is impossible to summarise psychoanalytic theory adequately without writing a book on the subject.

A further difficulty arises when one tries to justify Freudian theory to people who are either scientists or have a scientific turn of mind. They undoubtedly possess a clear picture of classical scientific method, and in Pavlov's experiments they will find one of the best models of the technique. In Freud's work, on the other hand, one is apparently dealing with the intangible; the units are emotions, drives, complexes or ideas. There is no laboratory background to cut out extraneous factors; there are not always any clear-cut results, rarely any experimental work and ordinarily no controls.

Whoever would justify psychoanalysis must justify both its hypotheses and its methods. Freud's background was the clinic or the consulting-room, Pavlov's the physiology laboratory, and what is possible in the one situation is impossible in the other.

Behaviourism and the conditioned reflex

Behaviourism as a movement began in Russia at the turn of the century with the work of Pavlov who was, in fact, a physiologist. His basic discovery was the conditioned reflex, which he demonstrated by showing that a dog which salivated at the presentation of meat (the unconditioned stimulus) but did not salivate at the sound of a bell or some other neutral or conditioned

stimulus, could be made to salivate to the bell alone after 20 or so repetitions of pairing the two stimuli. American psychologists first heard of Pavlov's work about 1909, but it was mainly through the work of another Russian, V. M. Bekhterev, as expressed in his book "Objective Psychology" — that the theory of conditioning first took root in the States. There it was seized upon with great enthusiasm by J. B. Watson, who wished to remove from psychology all subjective material and reduce it to "the science of behaviour."

The conditioned reflex was obviously the most satisfactory explanation of learning and habit formation and remains so today, although psychologists are not agreed that it is the only one. Learning by trial and error—which may be identical with conditioning—and insight, emphasised by the Gestalt psychologists, are alternative methods.

I, for one, find no conflict whatever between the work of Pavlov and that of Freud except that Freud, dealing with human beings, necessarily had to go beyond Pavlov to formulate hypotheses. And these, like all hypotheses, require correction from time to time in the light of new knowledge. Furthermore, I accept Eysenck's definition of neurosis as based on "maladaptive conditioned responses." This has been echoed in the psychoanalyst Karen Horney's definition of neurotic behaviour as characterised by rigidity. Whereas the normal individual behaves in a flexible manner appropriate to the requirements of a situation, the neurotic brings to all human relationships *"a tendency to act in predetermined ways"*—that is, in terms of past conditioning.

Much of the Freudian theory of neurosis can be explained in terms of conditioned reflexes which have replaced the sort of discriminatory behaviour necessary to the higher mental functions. This, in fact, is the meaning of the term "fixation." Professor Eysenck did not mention another element in neurosis asserted by Freud and demonstrated experimentally by Pavlov—the element of conflict.

Pavlov trained a dog to salivate by giving it food whenever a circle of light appeared; thereafter the dog salivated on presentation of the circle alone. But when shown an elliptical patch of light, the dog was not fed and hence acquired the habit of not salivating. After the animal had clearly differentiated between the circle and the ellipse, the latter was made more and more circular, until the dog's powers of discrimination broke down: it salivated without restraint, barked, whined, and struggled to get out of its harness. This was interpreted by Pavlov as being an experimental neurosis. It not only supports Freud's thesis that conflict forms an element in all neurosis, but also supports the Freudian concept of "regression" — the tendency in neurosis to revert to more primitive and uncontrolled forms of behaviour.

Freud and Pavlov were both materialists, both determinists. Their work was carried out under different circumstances and upon different materials. Freud permitted speculation and the creation of wide-ranging hypotheses. Pavlov kept close to the facts with short-range theories. But in important respects Pavlov's work confirms that of Freud, and it is only when we reach the absurdly oversimplified views of the American Behaviourists that any clash arises with psychoanalysis.

The nature of neurosis

I have already admitted that I have no quarrel with Eysenck's definition of neurotic symptoms as maladaptive conditioned responses. However, so far as human beings are concerned, the definition does not go nearly far enough.

A psychoanalyst might broaden Eysenck's definition of a neurosis as follows: a neurosis is a series of maladaptive conditioned responses to other people or oneself arising from early experiences, primarily in the family or family substitutes, which becomes overt when the individual meets analogous situations in later life, and which therefore results in mental conflict and symptom formation.

The Oedipus complex

Most of the cases of impotence I have come across have arisen in men who were unduly attached to a possessive mother; this situation leads after puberty to the division of all women into two classes — those who are sexually attractive but naughty, with whom the patient is able to be normally potent, and those who are "nice" and "good" like mother, with whom any sexual contact would seem incestuous. Yet this, of course, is the type they usually marry and with whom they are impotent. The associations are: goodness and respectability with absence of sex feeling, naughtiness and prettiness with sexual desire. These, if you like, are conditioned reflexes.

But Freud would go further and ask: "Why should incestuous feelings be associated with guilt?" He would answer: "Because at one time the little boy during the fourth or fifth year did, in fact, have sexual feelings towards his mother as his first love object, and since love aims at total possession he was also jealous of his father and, in spite of the love he also bore him, often wished him out of the way. Feelings of guilt caused him to give up the struggle, to regard sexual desire towards his mother as sinful and turn his attentions elsewhere." This is the famous Oedipus complex, well based on clinical observation, although the form it takes varies from one society to another.

Now none of this contradicts the theory of conditioning. It shows that neuroses are maladaptive responses in relation to people, based on conditioning during the first five years of life, and that these always involve conflict, ordinarily between primitive drives and socialised attitudes. Although these conditionings are maladaptive, they lead to some sort of adaptation which the patient is unwilling to give up for the same reason that a drowning man clutching at a straw may well be afraid to risk swimming to a much safer log some distance away. The symptom is a compromise solution to the conflict —for example, impotence of our patient kept him from performing an act which he had been conditioned to regard as evil. Indeed, in psychoanalytic practice, one of the greatest barriers to treatment is the patient's "wish to fall ill" because his symptoms have a purpose.

Behaviour therapy regards all this as wholly untrue, asserting that the symptom *is* the neurosis, that it arose

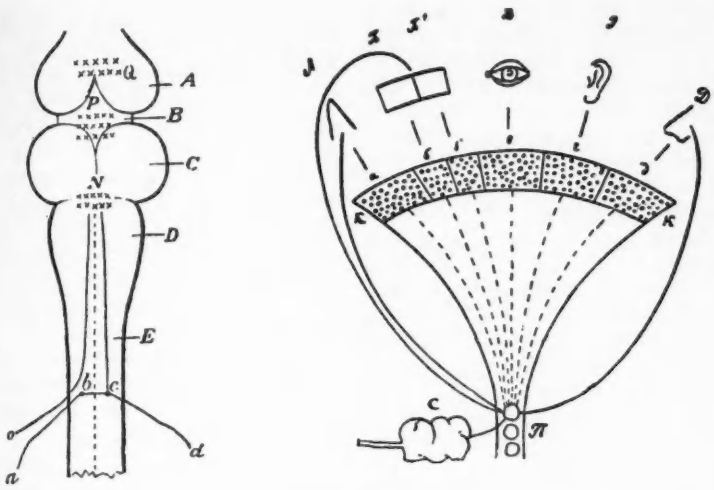


Fig. 2. Ivan Pavlov (*right*) was concerned with the neural mechanisms underlying behaviour. His most notable contribution was the conditioned reflex. Above are two of his earliest diagrams (1863), showing how the animal makes adaptive adjustments to its environment by means of new links between the cortical analysers and connections from them to subcortical, unconditioned reflex arcs. Behaviour therapy is largely concerned with removing "harmful" conditioning.

by conditioning alone and can be removed in the same way—a statement which the vast majority of psychiatrists, whether they approve of Freud or not, regard as nonsensical.

The origin of the conditioned response

The first case of a neurotic disorder described in Professor Eysenck's article is that of Mrs. Jones who is terrified of birds: "Seeing a bird—even the most inoffensive little sparrow—produces in her a fear so excessive that she has severe palpitations, may even faint, and feels such a strong compulsion to run away that she cannot always control herself." The fear, we are told, has existed for thirty years and has practically ruined her life, since she cannot go out and has to keep her curtains drawn lest a bird should alight on the window-sill.

Now this is a pretty devastating state of affairs to result from a single conditioned reflex, but we feel frustrated at not being told how the conditioning arose. Since, as I understand Professor Eysenck, the conditioned stimulus must always be the same (or very similar) in order to lead to the response—a bell, a flash of light, a loud noise, etc.—we are led to suppose that at some time in her life Mrs. Jones learned to associate birds with unconditioned fear. But he does not tell us what the situation was, although one would have thought it important and discoverable by hypnosis, which Eysenck has also studied.

We do not even learn whether the lady was cured, although the suggestion is made that "we might start talking to her about birds in a quiet, relaxed discussion; after a while we might introduce small pictures of parts of birds at a distance, gradually working up to pictures of real birds brought nearer and nearer . . . " and so on through films, stuffed birds, to tiny live chickens at the other end of the room. But if the phobia or irrational fear aways arises in the presence of the identical object (or a closely similar one) which originally brought it about, how are we to explain the phobia of snakes in people who have never met a snake or the almost universal fear of spiders among women who have never once been harmed by a spider?

Above all, how are we to explain the common phobias such as claustrophobia (the fear of enclosed spaces), agoraphobia (the fear of open spaces) or the fear of crossing streets? Is it seriously maintained that patients showing these symptoms have literally been conditioned by being shut up in cupboards, lost in the desert, or just missed being knocked down by a car?

The Freudian interpretation does not deny that these objects or situations arouse fear, but postulates that they are symbols concealing what the patient really fears: the claustrophobic is terrified in enclosed spaces, not because he has actually been frightened in one, but because they represent to him a fear of being "shut in" and overwhelmed emotionally by his relatives and friends, causing him to lose his sense of identity. The agoraphobic

with his fear of open spaces really fears being alone (as is confirmed by the fact that most severe agoraphobia disappears if the patient crosses the wide space with even a small child holding his hand).

Even more extraordinary are the types of case described in Professor Eysenck's article; as other psychiatrists have pointed out, they are all monosymptomatic neuroses, and on the theory that the symptom *is* the neurosis the patients must all be regarded as entirely normal people except for just one annoying symptom. Now, in the first place, the patient who even *appears* to have a single symptom is increasingly rare, while, secondly, no such person exists in reality since the existence of a neurosis invariably implies a state of maladaptation in interpersonal relationships. That, in fact, is what a neurosis is. The type of neurosis most commonly seen today has no overt symptoms at all; for the patient's problems are behavioural ones existing in his defective associations with others.

Other short methods of therapy

Assuming for the moment that the symptom and the neurosis are the same thing, that the patient is cured by the removal of the symptom, one is puzzled to understand why all the paraphernalia of modern behaviour therapy is necessary at all. Many symptoms are not at all difficult to remove by methods which are much simpler than that suggested in the case of the unfortunate "bird lady." In her case it would have been necessary to hunt around for pictures of parts of birds, stuffed birds, films of birds, and, finally, live chicks a few days old—a scene worthy of a Marx Brothers film. Not having met the lady, I do not know by what other means her symptom could have been removed. But it is more than probable that hypnosis would have done so, and it certainly would seem a simpler and more effective way of removing symptoms, if that is the ultimate end of therapy.

One of the very first people to employ behaviour therapy was Sigmund Freud himself in the early case of Anna O. who had an hysterical paralysis of the arm. He was able to find that the "conditioning" occurred whilst Anna was sitting somnolent by her father's deathbed with her arm hanging over the back of the chair, when it had "gone to sleep." Allowing her to talk over the incident in peaceful surroundings caused the paralysis to disappear.

This is one of the methods of "deconditioning" approved by Professor Eysenck, who specifically mentions "sympathetic listening" and "talking in a quiet, relaxed discussion." This is what others describe as psychotherapy, and I am glad to find that he approves of it.

What Freud said

Briefly, Freud described the individual's character structure as the result of a three-cornered struggle between the *id*, or primitive unconscious drives, the *superego* or conscience whose standards are often largely unknown to the conscious self, and the *ego* which brings together the demands of the real world, of id, and of superego and attempts to integrate them. That is to say, the nuclear personality which is formed in the first five years of life arises from compromise formations between primitive and socially forbidden impulses, the conscious mind's apprehension of the world of reality as it sees it, and the superego as representative of the ethical views of society.

Freud as a materialist did not believe that these were actual entities but rather processes going on in the brain, and as a determinist he believed that every human act had a cause which was theoretically discoverable. These causes were traced by the process of "free-association" in which the patient was encouraged to talk, apparently at random, but actually revealing his latent complexes.

He also described some of the stereotyped means whereby compromise solutions are reached in the three-cornered struggle. These he called "mental mechanisms," and most people will recognise their existence in the behaviour of others, if not in themselves.

In *displacement* an emotion which is frustrated in reaching its original goal is displaced on to another object; the man who cannot answer back to his offensive boss takes it out of his wife when he returns home. The popular phrase is "kicking the cat." Another form of displacement is the phenomenon of "love on the rebound."

Projection means that we project elsewhere those impulses which we cannot tolerate in ourselves; thus it is well known that sexually frustrated people see sexual suggestions all around them, whether they exist or not. The old maid who fears that there may be a man hidden beneath her bed is a national joke only because we are all Freudians at heart and realise that she would not have the fear if she did not unconsciously have the wish.

In *conversion* we solve a conflict by turning it into physical symptoms, and this is the meaning of the (increasingly rare) conversion symptoms of hysteria. The man with writer's cramp finds that he is unable to write although he can still use a knife and fork which employs the same muscles. Perhaps he has a job which he dislikes but, because of a conscious sense of duty and family commitments, will not admit to desiring to leave. So his hand "goes on strike" and resolves the conflict by satisfying both his conscience (he is after all "ill") and his unconscious wish to get out of an intolerable situation.

All symptoms are such compromise solutions and the danger of behaviour therapy is that it fails to recognise this.

The results of treatment

Figures relating to the relative results of treatment are notoriously unreliable, depending upon how one defines a neurosis, the type of patients selected, and the differing criteria of cure. Thus to psychiatrists in general a case of impotence is a neurosis when the man concerned is either impotent with all women or impotent with his wife under all circumstances. Since any man may be impotent under some circumstances, Professor Eysenck's case of a man who was disturbed purely by the associations of the wall-paper in his bedroom would not ordinarily be considered as a neurosis at all any more than it is a neurosis to have a strong distaste for sago pudding because nurse insisted on us taking it during childhood. If these are neuroses, small wonder that Wolpe

(another exponent of behaviour therapy) claims 90% of improved cases as contrasted with only 60% for those treated by psychoanalysis!

The fact is that the human organism, like any other, always tends towards some sort of adjustment or equilibrium with its environment, and the neurotic tends to do so as much as anyone else. His adjustments are always faulty in the technical sense but a new one may be less so in the social sense. The case of accident neurosis "recovers" following the settlement one way or another of his compensation claim. To another patient the prospect of remaining indefinitely in hospital may bring about an adjustment in the long run in favour of returning to work. Again, the death of a marital partner or other relative who has been the immediate instigating cause of the neurosis may cause loss of symptoms. But none of these events change the basic personality structure. The first case is as liable as before to make further claims or to excuse himself from unwanted tasks on the grounds of the past breakdown; the second will evade reality similarly and the third will show symptoms once more when the same or similar type of individual re-enters his life.

As circumstances alter so does the neurosis, but the defective attitude to human relations that it conceals does not.

Psychoanalysis is today first and foremost a method of investigation and a hypothesis with many practical applications which have permeated most branches of contemporary thought. It is a theory of personality used widely by psychiatrists of all shades of opinion in order to understand certain forms of mental illness. Most forms of short therapy, for example, make use of the theory without necessarily employing the time-consuming methods. Personality tests such as the Rorschach, Thermatic Apperception, and Szondi (widely used in personnel selection) are based upon it; and it is even used commercially in the form of motivational research.

So far as a complete method of treatment is concerned, Freud accepted the fact that it was only suited to a limited number of cases but that, applied successfully, it was the most radical form of cure known and the only one which can alter the basic personality structure. In the form of group analysis, it can be applied to many more patients. Hypno-analysis, with or without the use of drugs, increases the number.

Much of modern social science and a great deal of anthropology would be at sea without Freudian theory, and few of us realise how different the world would appear had Freud never been born. Professor O. L. Zangwill, who is a scientific psychologist concerned only with scientific criteria of truth and by no means unreservedly committed to the Freudian viewpoint, can nevertheless write in his *Introduction to Modern Psychology:* "As a result of Freud's researches psychology today differs from psychology of fifty years ago in a manner so fundamental as to justify comparison with biology before and after Darwin."

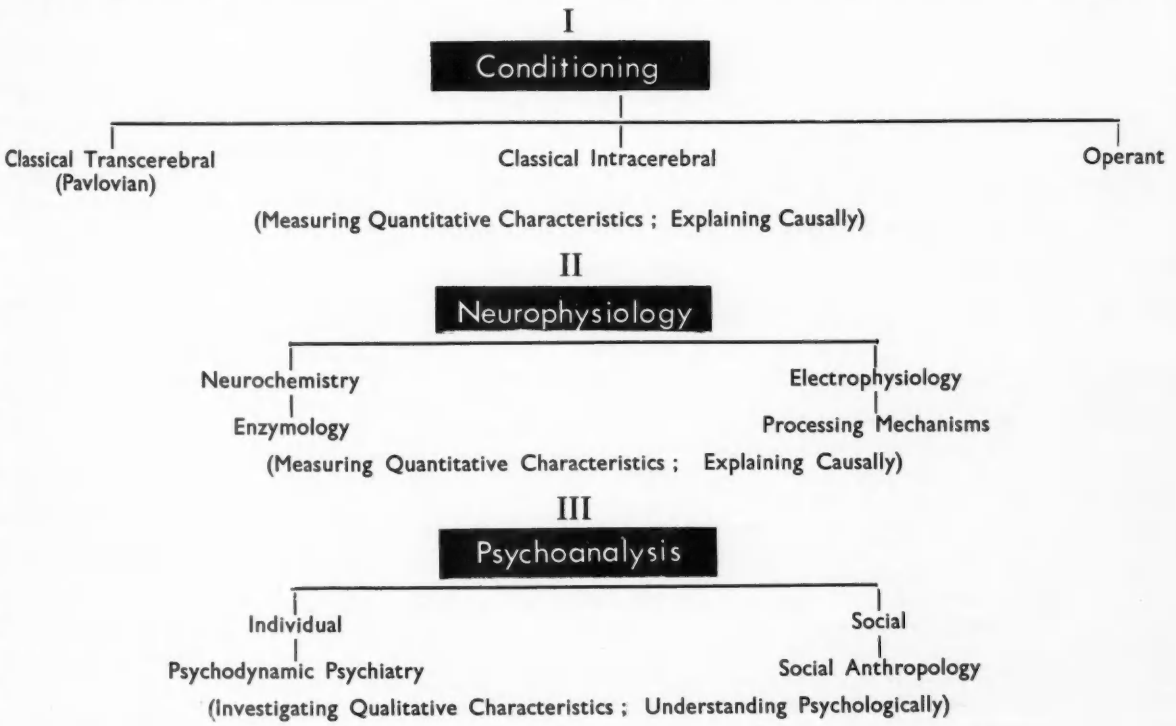


Fig. 3. This table shows the main procedures underlying today's behavioural research, and the three concepts from which they have sprung. The name of Pavlov is closely connected with the first, and that of Freud with the third.

Environmental control of reproduction

R. L. HOLMES

The sexual cycle of many animals can be controlled by environmental factors—by light, by temperature, and by "social" and "psychological" pressures. These are now throwing light on the chemical mechanisms underlying reproduction.

Seasonal variation in the reproductive activity of living creatures is a widespread and familiar phenomenon. In the spring, for example, many birds go through the often complex patterns of courtship display and nest building before mating occurs. Many mammals, such as wild rabbits, also breed in the spring ; others, such as sheep, mate in the autumn, and give birth to young in the early part of the following year.

Patterns of breeding activity vary between different species. Thus some mammals have only a single period of heat, or oestrus, during the year ; others, such as rats, become oestrous every four or five days so that unless pregnancy occurs possibilities for fertile mating recur frequently—hence the prolific breeding of such animals under natural conditions.

The reproductive cycle itself is directly under the control of hormones secreted into the bloodstream both by the pituitary gland and by the ovary. The secretion of these hormones, and hence the rhythmic alternation of sexual activity and quiescence, is regulated by some inherent mechanism, or "biological clock", which is normally set to give a relatively constant pattern of reproductive activity for any one species of animal.

The action of this inherent mechanism can however be modified, thus changing the timing of the reproductive cycles. For example, injections of stimulating hormones can induce oestrus at an unusual season ; less directly, modifications of the environment may accelerate or retard the onset of oestrus, and external stimuli, acting at any rate to some extent through the nervous system, can modify the activity of the endocrine organs.

The effects of light

In 1925 Rowan[1] published a series of observations on Junco finches in which he showed that by exposing these birds to increasing periods of illumination in the winter months, when day length is naturally decreasing, the gonads could be prematurely brought into breeding condition. Furthermore, he found that this activation occurred despite the fact that the birds were exposed to the low temperatures of the North American winter, so that light appeared to be a dominant factor in accelerating the normal reproductive cycle.

In 1932 Bissonnette[2] published his first observations on the effect of light on the reproductive cycle of the ferret, an animal which has proved to be particularly suited to studies of this kind. Female ferrets usually come into oestrus in March and remain in this condition until August or September, when they become sexually quiescent (or anoestrous) until the following spring (*see Fig. 1*).

Bissonnette showed that female ferrets exposed to six hours or so additional light during the dark evenings from October onwards came into full oestrus two months or more ahead of the usual time. Male animals can be stimulated in the same way, and successful breeding can occur between males and females conditioned by light in this manner.

Despite this striking effect of increased illumination on reproductive cycles, induction of early oestrus does not depend only on the amount of light to which animals are subjected. Indeed, ferrets exposed to 14 hours of light followed by ten hours of darkness each day come into oestrus more quickly

than animals kept in constant light. Neither is light an all-important stimulus, since ferrets kept in total darkness for 23½ hours each day may still attain full oestrus the following spring, as may also blind animals. Thus there appears to be an inherent rhythmic alternation of sexual activity and quiescence, whose timing can be modified by light.

Increased periods of exposure to light are not stimulating to all species, and some animals such as sheep and goats (which normally breed in the autumn) are influenced by daily diminishing periods of light, and can be brought into breeding condition prematurely by exposure to artificially short days during the early summer when days are naturally lengthening.

The effects of temperature

Although Rowan showed that in finches light was a dominant factor despite low environmental temperatures, temperature itself, which in many parts of the world fluctuates considerably throughout the year, is a potent factor for some species, including amphibia, birds and mammals. In birds the occasional late autumn breeding in unusually mild seasons observed in resident British species shows that unseasonable warmth can override the usual inhibitory effect of short days on the breeding cycle. Among mammals, the ground squirrel of North America exhibits a reproductive cycle which is dependent on temperature and independent of light. The gonads of this animal regress in spring and early summer as the temperature rises and attain breeding condition only under conditions of low temperature, whether natural or artificially produced.

Low temperatures also affect the time at which some animals reach sexual maturity. Puberty, as judged by the time of breakdown of the membrane which closes the vagina in immature mice, occurred seven days later in a group of animals reared at a temperature of −3°C. The onset of oestrus was also delayed in animals of the former group, and individual oestrous cycles lengthened.

Food and other factors

Other physical environmental factors may also influence the reproductive cycle. Rainfall and humidity, as well as temperature, affect the time of breeding of frogs, and it has been suggested that migration of these amphibia to their breeding ground is stimulated by chemical factors in the water arising from a type of alga which grows at only one season of the year. It has also been suggested that hibernation in hedgehogs, which is accompanied by sexual quiescence, is influenced by barometric pressure.

External stimuli will not, however, affect the reproductive system equally at all times in any species, and in many birds and mammals a refractory period ensues after breeding during which it is impossible to induce development of the reproductive tract by environmental factors.

Food, which is in any event essential for life, must be available in adequate amount if normal reproductive cycles are to be maintained. This is particularly apparent in the case of hens, where the number of eggs laid is directly related to the intake of food. Disappearance of rabbits due to myxomatosis caused foxes to prey heavily on small rodents which form the natural food of owls, with the result that fewer chicks of these birds were fledged. Food, however, does not seem to act as a direct stimulus to gonadal activity, although the provision of abundant food for sheep ("flushing") is widely believed to increase their reproductive capacity. Restriction of food, on the other hand, will result in a delay of sexual maturation.

Domestication has resulted in modification of the sexual cycles of many animals, probably by ensuring that they are provided with a good supply of food throughout the year, together with a sheltered environment. Thus although wild rabbits breed mainly in the spring, and possibly again in August, domestic rabbits if well housed and fed will breed the whole year round. Similarly cats usually go through two or three periods of oestrus a year, but the wild cat has

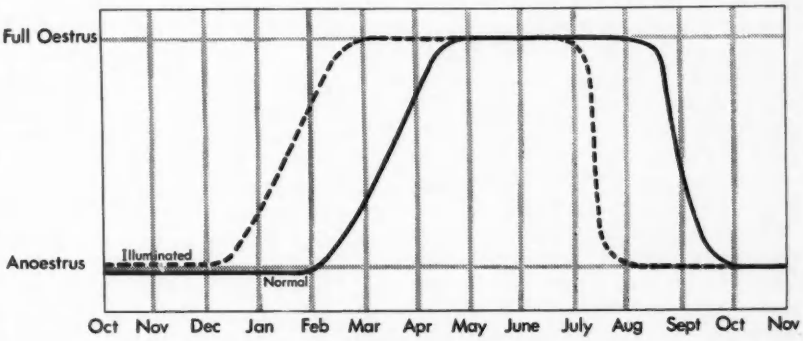


Fig. 1. By exposing female ferrets to regular light stimuli their normal oestrus cycle is brought forward by as much as two months. Male ferrets' sexual activities can be stimulated in the same way.

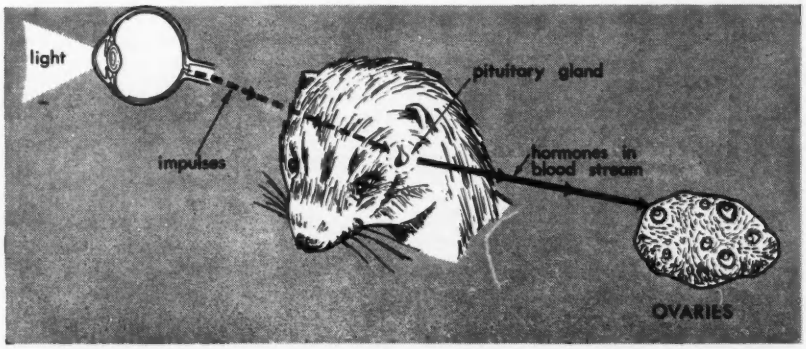


Fig. 2. The pathway by which light stimulates the ferret's reproductive cycle has now been traced through the pituitary gland, though other parts of the endocrine and nervous systems are almost certainly involved. The pituitary gland is situated immediately below the hypothalamus.

only a single oestrus, in the spring.

Lord Medway[3] has recently investigated the factors responsible for the maintenance of brooding behaviour in pigeons, which is normally associated with the presence of eggs in the nest. He found that substitution of any solid model which approximated in size and shape to the natural egg was effective in stimulating brooding behaviour but that flat oval models, or even the eggs themselves if physical contact with them was prevented, were not effective. The stimulus provided either by natural eggs or by acceptable models did not however appear to depend on tactile perception, since total denervation of the skin of the apterium (that part of the breast of the bird that covers the eggs during brooding) did not prevent brooding behaviour. He concluded that the maintenance of broodiness is dependent on the continued recognition of the presence of at least one egg by the bird, by whatever means available to it, and not on any specific pattern of stimulation of a restricted class of sensory receptors.

Prior to this work it was already known that the number of eggs in the nest may be an important factor in determining the cessation of laying, which in many birds takes place as soon as the customary number of eggs in the clutch has been laid. If eggs are removed daily from the nest, laying may continue until the ovaries are exhausted, so that a bird such as the house sparrow, whose clutch usually consists of 4-5 eggs, can be induced to lay as many as 50 in succession.

Social factors

A second group of factors which may greatly influence reproductive activity can be classed as "psychological" or "social", and includes stimuli derived from the environment, and particularly those derived from the presence of other living creatures.

Medway, for example, has demonstrated the striking effect of purely visual stimuli in inducing brooding behaviour in pigeons. In his experiment a broody male pigeon was caged so that it was separated from a female bird, but could be seen by her. Medway found that the female continued brooding behaviour so long as, but no longer than, such behaviour was shown by the male.

Inclusion of members of the opposite sex in a cage with either male or female birds induces greater growth of the gonads in either sex than if the birds are caged alone. In pigeons ovulation is totally inhibited if a female is caged in isolation, but it is induced by the presence of a male. It is still induced, but more slowly, by the presence of another female, and is also induced, although yet more slowly, if a mirror is placed in the cage with the isolated bird.

Another example of the social factors influencing reproductive behaviour is the effect of the presence of potential mates, which in many birds can act as a stimulus to gonadal development. Often full testicular development in the male is attained before the female is receptive. The male bird, often brilliantly plumed, then puts on an elaborate display before the female, which may act as a stimulus to ovulation. Among mammals, the presence of a ram will stimulate the onset of heat in ewes.

Recent work has shown that under artificial conditions also the presence of other members of the same species may modify the reproductive cycle. Chitty and Austins have studied colonies of voles bred in captivity and found that when animals were kept in single breeding pairs, or in groups of a single litter each, the females underwent multiple short oestrous cycles similar to those of rats and mice, and that sexual receptivity was limited to one part of the cycle. When the animals were kept in larger groups the females showed prolonged periods of oestrus such as occur in rabbits and cats, instead of short regular cycles.

Comparable findings have also been reported in mice, in which grouping produced a highly significant reduction in the incidence of oestrus. Brucer has also shown in mice that the introduction of a strange male into the cage of a female mated less than 24 hours previously often results in the inhibition of implantation of the fertilised egg in the uterus, thus blocking the pregnancy. This effect did not follow the introduction of the original stud male into the cage, nor the introduction of a strange female ; indeed there was some evidence that the presence of other females had a stabilising effect on the pregnancy.

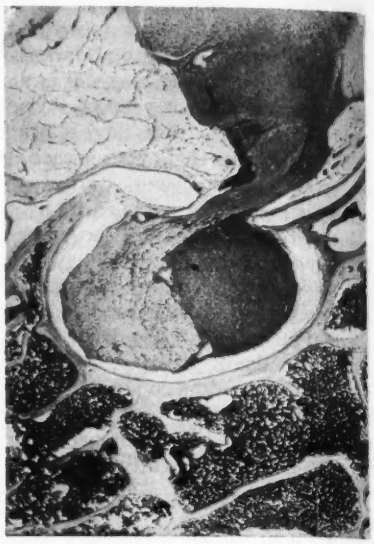


Fig. 3. The pituitary gland of a monkey, lying in a "cup" at the base of the brain. On the left (light grey) is the neural process ; on the right (dark grey) the pars distalis. The pituitary stalk connecting the gland to the hypothalamus at the top of the picture can be clearly seen.

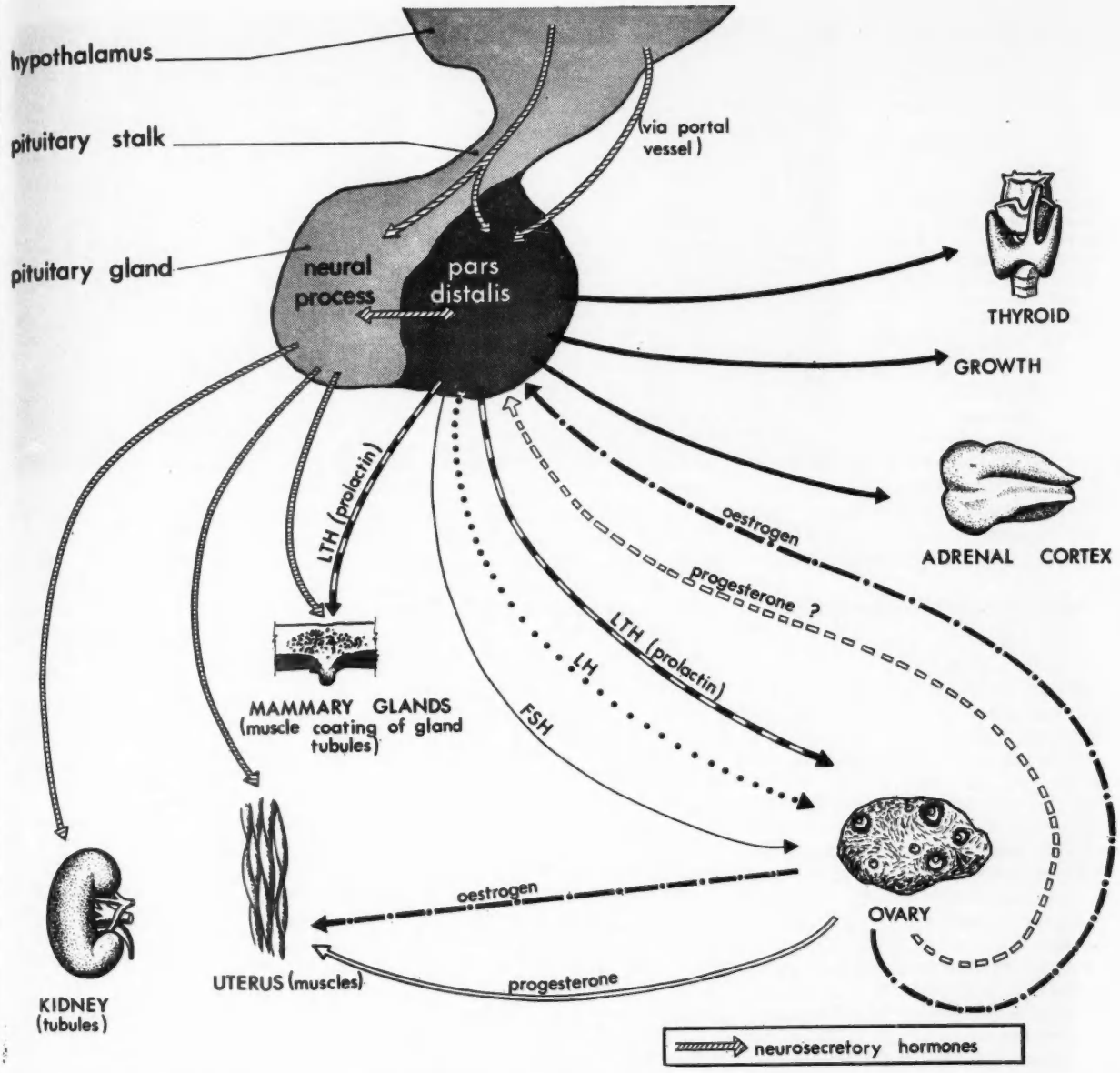
Fig. 4. The main hormonal pathways connected with the control of reproduction and the reproductive cycle. An explanation of the diagram is given in the text on page 503.

Many species fail to breed in captivity, despite the fact that they are in good health and well cared for. This failure may be due to lack of stimuli to gonadal development and reproductive activity which in the wild come either from the physical environment, or from other living creatures.

How do environmental stimuli act?

The few examples chosen from an extensive literature show that many environmental factors, both physical and social, can modify the reproductive cycle. But these observations pose a major problem : how do the various stimuli exert their effect on the organism, and particularly on the reproductive system?

It is now clear that the solution to this



problem lies in the pituitary gland and in a closely related part of the brain. The pituitary gland itself is a complex secretory organ lying in a hollow in the bony floor of the skull immediately below the hypothalamus (*see Fig. 3*). It consists of a number of different parts, but only two of these are of major importance in the present context, namely the anterior division, or pars distalis, and the posterior, or neural process.

The neural process is connected to the overlying hypothalamus by the pituitary stalk, down which pass fibres from certain groups of nerve cells in the hypothalamus. These fibres carry hormones manufactured by the nerve cells—the neurosecretory cells—and liberate these into the blood which passes through the vessels of the neural process. These hormones circulate in the bloodstream, and control among other things the reabsorption of water in the tubules of the kidney, and the contraction of muscle in the reproductive tract and mammary glands.

The pars distalis is closely connected to the neural process, but its connection with the nervous system appears to be mainly through a system of blood vessels—the portal vessels which collect blood from a capillary network in the floor of the hypothalamus near the origin of the pituitary stalk, and conduct it to the anterior part of the gland. This "portal system" was at one time considered to be completely isolated from other blood vessels, but it has recently been shown that in fact it communicates with other vessels in the hypothalamus, and also with those

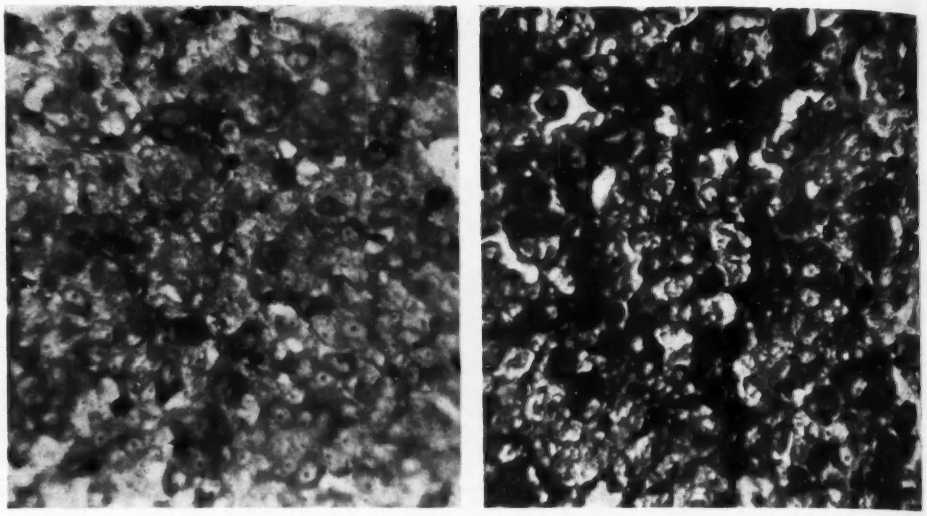


Fig. 5. Photomicrographs of comparable regions of the pituitary glands of two female ferrets. (Left)—anoestrous : the cells stain palely as there is little glycoprotein material in them. (Right)—oestrous : the whole gland is full of cells which stain strongly for glycoprotein. These are the gonad-stimulating cells. (Mag. x 400.)

of the neural process, a finding which may necessitate a re-evaluation of the functional importance of the system.

Hormones of the pars distalis

The cells of the pars distalis secrete into the bloodstream at least six different hormones (*see Fig. 4*). Three of these are concerned respectively with regulation of growth of the body, with control of the thyroid gland, and with control of the outer or cortical parts of the adrenal glands. The other three—follicle stimulating hormone (FSH), luteinising hormone (LH) and lactogenic hormone (LTH) or prolactin — are more directly concerned with the regulation of the reproductive system.

At the beginning of a typical sexual cycle FSH acts on the ovaries and stimulates the growth of follicles containing the ova to a stage at which they are sufficiently mature for ovulation to occur. At the same time the ovary is stimulated to secrete a hormone, oestrogen, which acts on the reproductive system and in mammals brings about changes in the lining of the uterus in preparation for the reception of a fertilised ovum, should fertilisation occur. At the same time oestrogen acts on the pituitary gland and stimulates it to produce LH, which acts together with FSH and causes the release of mature ova from the ovarian follicles. LH also stimulates the cells of each empty follicle from which an ovum has been liberated to develop into a glandular structure, the corpus luteum. The corpus luteum then secretes a second ovarian hormone, progesterone, which completes the preparation of the uterus for the reception of a fertilised egg. In the rat, and possibly other species, secretion of the corpus luteum is under the control of prolactin, which is also called the luteotrophic hormone. Prolactin is also responsible for maintaining the secretion of milk from the mammary glands at the end of pregnancy.

There is considerable evidence that most if not all the hormones which are secreted by the pars distalis of the pituitary gland are produced by different types of cells, and in some animals at any rate it has been possible to determine the cellular site of origin of some of the individual hormones. It is known, for example, that three of these compounds—FSH, LH and the thyroid stimulating hormone—are "glycoproteins" ; that is, they are complex substances which contain both carbohydrate and protein combined in their molecules. Furthermore, it is possible to stain glycoprotein selectively, so that its presence can be detected by microscopic examination. By applying this selective staining method to the pars distalis it is therefore possible to identify the cells which contain glycoprotein, and hence those cells which probably produce and store the glycoprotein hormones.

During the winter period of anoestrus the amount of glycoprotein material in the gonad-stimulating cells of the ferret's pituitary gland is small, and these cells are inconspicuous. In the spring when the animal is coming into oestrus these cells become packed with heavily staining glycoprotein (*see Fig. 5*). Thus a seasonal increase in prominence of these cells accompanies the increased production of gonad-stimulating hormones by the pituitary gland, and it is these hormones which act upon the reproductive system and bring the animal into oestrus.

Removal of the pituitary gland from a female ferret prevents both the onset of normal spring oestrus and also the stimulating effect of additional light during the winter months. Further studies have shown that exposure of female ferrets to additional light in winter results in a marked increase in the amount of stainable glycoprotein in the gonad-stimulating cells of the pars distalis. Thus there seems little doubt that light affects the reproductive system via the pituitary gland (*see Fig. 2*).

The role of the eyes and hypothalamus

The eyes have also been shown to play an essential role in the reaction of anoestrous ferrets to light. Blind animals will not respond to additional winter lighting by coming prematurely into oestrus, although they still come into oestrus at the normal time. Thus we can identify the two ends of the pathway by which light causes the

liberation of gonad-stimulating hormones (the eyes and the pituitary gland), but are left with the major problem of tracing the path taken by the stimulus between these two organs.

There is a considerable body of evidence that the hypothalamus is concerned in the mediation of environmental stimuli which affect the pituitary gland, although the precise role played by this part of the nervous system is far from clear. A major difficulty in studies of the function of the hypothalamus is that many groups of nerve cells are concentrated within this small region of the brain, and these cells have widespread connections with other parts of the nervous system. Lesions of the hypothalamus may profoundly affect the activity of the whole of that part of the nervous system which governs the internal functions of the body, and may result in disorders of temperature regulation, water balance, and appetite, as well as modifying sexual behaviour. Similarly, artificial stimulation of this part of the nervous system may alter the level of secretion of hormones from the pituitary gland and may also modify the functions of other internal organs.

As already described, processes of some of the nerve cells of the hypothalamus pass down the pituitary stalk and end about the blood vessels of the neural process. This pathway between the nervous system and the posterior part of the pituitary gland has been extensively studied, and found to be present in all vertebrate animals. Recently it has been claimed that processes of some hypothalamic nerve cells pass only as far as the basal region of the hypothalamus, and end in close relationship to the capillaries through which blood passes to the portal vessels. It has been suggested that such a neurovascular link might act as a route by which nerve cells in the hypothalamus could influence the activity of cells of the pars distalis.

Species variation and human reproduction

A major problem in endocrinological research is the variation between species which makes it unwise to apply directly results obtained from the study of one kind of animal to another, even if, like rats and mice, the two are closely related. Between animals of different orders such as the rat and the ferret, differences are likely to be even more marked ; but perhaps the greatest pitfalls lie in attempts to apply results gained from animals to man. At best we can only hope to approximate as closely as possible to the human organism by studying primate species, which alone of mammals have, for example, a menstrual cycle comparable to the human one.

In man there is no clear-cut indication of breeding and non-breeding seasons, and hence no firm evidence of any effect of day-length or temperature on fertility at different seasons of the year. Yet some environmental factors can influence human reproductive activity, although the data from which conclusions must be drawn are often incomplete and the variables greater than in controlled animal investigations.

Environmental effects on man

Climate appears to influence the human reproductive cycle, since the onset of menstruation in girls is earlier in temperate zones of the world than elsewhere, and women in warm countries tend to marry and bear children earlier than those in cooler regions. It has been reported, on the other hand, that in hot and humid tropical zones there is a definite depression of gonadal activity.

In man, as in animals, chronic malnutrition depresses the gonadotrophic activity of the pituitary gland, and undernourished children have a delayed onset of menstruation. It is significant that in recent years there has been a general decrease in the age at which menstruation begins, probably as a direct consequence of higher standards of hygiene and diet. Psychological factors can also affect human reproductive cycles, and shock, worry or fear is commonly associated with irregularities of menstruation.

In conclusion, it is now evident that many variable environmental factors may affect reproductive cycles. Investigation of the importance of each individual factor requires that all other variables are standardised, so that the effect of varying a single environmental factor at a time can be studied. To this end, rooms in which physical factors such as light, temperature and humidity can be rigorously controlled are now being used to investigate the effect of environment on the reproductive activity of rats and ferrets. Social factors must also be taken into account, although it may be more difficult where these are concerned to recognise what is important.

Conclusion

Knowledge of the structure and functions of the hypothalamus and its relationship with the other parts of the nervous system is still incomplete, and the nervous pathways involved in the transmission of external stimuli from receptors to the hypothalamus are unknown. The mechanism by which the hypothalamus can modify the activity of the pituitary gland remains obscure, and chemical stimulating substances, proposed as mediators between the nervous system and the gland, have yet to be isolated and identified. Thus many problems remain to be solved before we can arrive at an understanding of how the nervous and endocrine systems act together to control the complex patterns of behaviour involved in reproduction.

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THE BOOKSHELF

On teaching mathematics.
Edited by Bryan Thwaites. (*Pergamon Press, 116 pp., 7s. 6d.*)
Education—divisible or indivisible?
Inaugural lecture by Bryan Thwaites (*Camelot Press, Southampton, 27 pp., 2s. 6d.*)

"For the truth is that the whole profession of mathematics is like a very sick man, a man in a high fever and so still restlessly active, but suffering even so from a wasting disease . . . In plainer language, if the present shortage of mathematics teachers at all levels of education is allowed to develop any further, there is a strong possibility that mathematical education, as we have known it in this country and in this century, will come to an end within twenty years, a possibility of incalculable consequences for the life of the nation as a whole." So said Professor Thwaites in his inaugural lecture at Southampton University on May 23, 1961, reprinted by the Camelot Press.

In support of this diagnosis he gave figures for the output of university mathematicians and for the staffing position in universities and schools. Existing mathematical departments in British universities require an annual intake of about 32 Ph.D's. to cover wastage from retirements. In 1960 the actual output of mathematical Ph.D's. was 59; but of these only 17 took up university teaching. Thus the present supply of university staff is only about half what would be needed to maintain the status quo, let alone to cater for the proposed expansion of universities about which we hear so much. The position in schools is much worse. A survey by the Incorporated Association of Headmasters covering 996 schools showed that these schools had 1,740 vacancies for mathematical school-teachers. Under normal circumstances, a grammar school may be expected to recruit a new mathematics master at intervals of between five and ten years; and this implies about 150 vacancies per annum in 1,000 schools. Thus the present number of vacancies is over ten times what it ought to be. Moreover, this figure for vacancies does not take full account of positions which are already filled by teachers with inadequate qualifications. To gauge the position from the point of view of requirements for qualified staff, consider the 1,400 secondary and direct grant grammar schools in the country, with an average of 550 pupils per school and requiring about five qualified mathematical teachers each. Such schools therefore require about 7,000 mathematical teachers altogether. By March 31, 1960, their actual complement was 4,000 graduates with degrees in which mathematics was the principal subject; and so they are 3,000 short. Since the country has about 2,000 schools which teach at grammar school level, the total deficiency of mathematics teachers may be about 4,500; and to this figure we ought to add a continuing requirement of about 250 graduate teachers per annum to cover retirements in a force of 7,000. The present output of mathematical graduates from British universities is about 700 per annum. At this rate it would take about 10 years to provide the schools with the staff they need, even if all graduates were compulsorily drafted into the teaching profession.

But, of course, compulsory drafting seems out of the question, if only on account of the very forces that have led to the present shortage. The prime cause is the recent industrial hunger for mathematicians, stimulated by the advent of the electronic computer. It is a very expensive business to develop a new industrial product, such as an aircraft or a nuclear reactor, and it is prohibitively expensive unless this development is preceded by elaborate theoretical studies to ensure that the work starts on feasible lines. Such theoretical studies involve considerable amounts of advanced mathematical analysis and vast quantities of computation. The cost of experimental trials and prototypes is much greater than the salaries of mathematicians and the expenses of running a computer. Hence industry is recruiting mathematicians at salaries which are beyond the reach of the educational profession. In the three years 1956 to 1959, 46 per cent of freshly graduated mathematicians went directly into industry. The 1957 White Paper on Scientific Manpower forecast that in these three years industry would increase its complement of mathematicians by 36 per cent. In the event the increase was 48 per cent. The 1959 White Paper forecast a further industrial increase of 40 per cent for 1959 to 1962; and there is every prospect that this forecast as well will prove an underestimate.

There is moreover a graver aspect: for industry requires technologists and engineers in much larger numbers than it needs mathematicians. These technologists and engineers must receive a sound mathematical education at school. And the incipient disintegration of mathematical schoolteaching therefore threatens the industrial export trade upon which the country depends so vitally.

In April 1961, Professor Thwaites was chairman of a conference held at Southampton for mathematics teachers from schools and universities together with mathematicians from industry: "On Teaching Mathematics" is a report of this conference. It considers what steps might be taken to improve the supply of mathematicians and to fashion a mathematical syllabus attuned to the demands of the second half of the twentieth century. These demands include not only those of industry and technology but also the many new applications of mathematics in the physical, biological and social sciences. The report was written by members of the conference, grouped into committees for individual chapters of the report; and it can fairly be called a document representative of the different sectors of the mathematical profession. It is largely non-technical in character, and it merits the attention of anyone who is concerned with the practice and the products of technological and scientific education whether he be teacher, parent or administrator.

The main conclusions of the report are that (*a*) the mathematical intake to universities should be doubled as from 1962. The Vice-Chancellors' Committee has convened a conference for September 1961 to discuss the feasibility of this; (*b*) there is a need for a national policy to co-ordinate the different educational sectors in mathematics, and to ensure that schoolteachers are kept up to date by regular retraining courses at universities after the pattern adopted by the National Science Foundation in the U.S.A.; (*c*) moulding and remoulding the syllabus to meet developments, and producing suitable textbooks both for schoolchildren and schoolteachers call for substantial full-time (and part-time) work by a largish body of well-qualified people as a national responsibility; and (*d*) there should be greater exchange of staff on sabbatical leave between schools, universities and industry.

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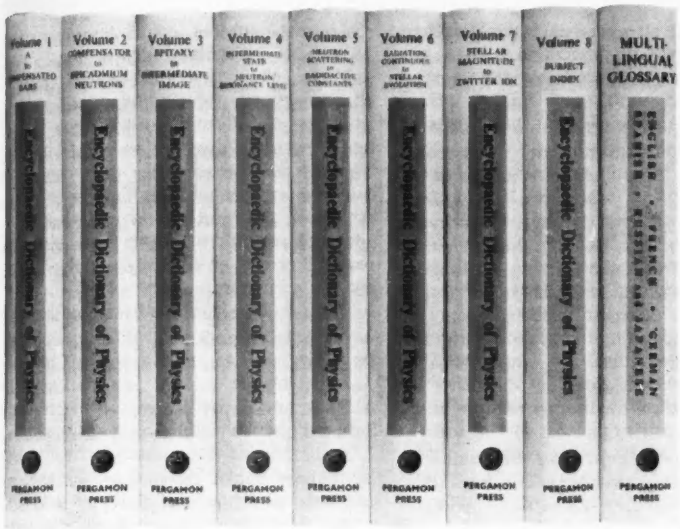

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the book has also been extensively revised. Recent growth of interest in soil zoology is strikingly evidenced by the number of references in this new English edition which is almost double that in the original.

The book is substantially unaltered in format and approach. In the foreword three types of work are recognised: systematics, work of "purely quantitative statistical nature," and thirdly, work which deals with the "living phenomena of soil organisms," especially the physiological and ecological aspects. Being an ecologist and an accomplished naturalist it is the third approach which Kühnelt adopts "since it alone is suited to the working out of the many-sided relationships" between organisms in the soil.

In the first chapter on Methods this essentially qualitative approach is evident. New and complex extraction processes are described but emphasis is placed on simple extraction techniques and on methods of direct observation. The second chapter occupies over a third of the text and is a somewhat encyclopedic survey of soil animals group by group and as such should be dipped into rather than read from end to end. Here is a wealth of bionomic detail which all undergraduates should read. Something of the magic one expects in accounts of freshwater and marine animals is present and will balance the usual texts where many of the commonest animals on the earth's surface are dealt with as afterthoughts. The exclusion of the subject bibliographies appended to each section in the original is perhaps to be regretted.

A third chapter deals with soil animals in relation to the physical environment and their own protective and other adaptive features. Here as elsewhere, the narrative does not depend on reference to innumerable graphs and tables but makes its many points in a most painless manner. The chapter on the living community of soil animals begins with two sections new to the revised edition—on Food and on Population Density—where productivity studies are discussed in so far as they concern rates of conversion. Conversion processes themselves—degradation of animal and plant residues—are then described; this section is the *piece de resistance* of the book. The succession of organisms in tree stumps, for example, is wonderfully described as also is the litter-decomposing community. These communities are no nebulous concepts but real entities engaged in a process. In the next chapter the colonisation of bare rock is recounted in the same fascinating manner and the whole process of soil formation discussed. The positive approach of these two chapters will reassure the student lost in the uncertainty of present-day community ecology.

There follow two short and interesting chapters on the significance of soil organisms for soil fertility and on the origin and geographic distribution of soil fauna. There is a species index with over six hundred entries with indication of their systematic position. It is indeed a great accomplishment to have produced so readable a text so liberally sprinkled with specific examples.

J. GORDON BLOWER

Art and the Scientist.
By Geoffrey Lapage. (*John Wright, 115 pp., 42s.*)
A Book of Science Verse.
Selected by W. Eastwood (*Macmillan, 279 pp., 21s.*)

Both these books are at least as much a challenge to artists and poets as to scientists. Mr Eastwood opens on the note that "a poetry which ignores science and its applications is, in the modern world, divorced from life"; Dr Lapage near the close of his book speaks of "the challenge which art must accept or die. It must grasp, and integrate into art, the rich material which science offers it." The ultimate aim of the two writers—the reconciliation of the artistic and poetic spirit with the scientific—is the same; but the nature of their respective contributions is rather markedly different.

In Dr Lapage's book this aim becomes prominent only towards the end; nearly four-fifths of the text are concerned with the certainly relevant, but in a sense somewhat peripheral, problem of the role of the scientist (especially the morphologist) in illustrating his own scientific

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Study at Home

The increasing importance of Science in industry, commerce and education opens up many worth-while opportunities for Science graduates. Wolsey Hall (est. 1894) provides postal tuition for the examinations leading to the B.Sc. degree of London University, for which residence at the University is not required. **Prospectus** (please mention examination or subject) from E. W. Shaw Fletcher, C.B.E., LL.B., Director of Studies, Dept. WM8,

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work, either with his own hand or with that of an artist closely directed by him. To explore this relationship the author provides a beautiful series of illustrations drawn from biological works ranging from the sixteenth century classic on the horse by Ruini down to such modern masters of the craft as J. H. Ashworth (line and colour display of the anatomy of *Arenicola ecaudata*) and Clifford Dobell (paintings of amoebae from the human intestine).

On a study of these pictures the author bases an informative account of the various techniques of illustration, with an assessment of the advantages and limitations of each in relation to the end in view—diagrammatic clarity, liveliness or formal precision of reproduction. This gives him the opportunity to discuss to what lengths the scientist may allow his artistic sensibility to go at the risk of distorting the "depersonalised" report which is commonly held to be one of the essential characteristics of science.

But what is "objectivity"? In "The Mind and the Eye" (which rather unexpectedly does not appear in the bibliography) that great artist-scientist-philosopher, Agnes Arber, revealed that she had looked for years at the umbel of *Anthriscus* without "seeing" the complex stellate pattern which the "seeing eye" can never forget.

Mr Eastwood's method is to allow the poets, great and small, to provide a sequence of reactions—a few adoring, some cursing, others (and it is good to see scientists among these) mirthful and satiric—to the expanding role of science. Some have tried to share the scientist's wonder and fulfilment (Ronald Ross strikingly expressed his own, and his subsequent disgust at the pettiness of mankind in the mass); others have described his revelations of the fabric of nature and the effects of technological change. To my jaundiced eye it is—with few exceptions—those who like Pope have sounded a deep warning against cosmic *hubris* who have reached the highest poetic level.

Both authors have made a valuable contribution towards the "harmonisation of divergent aims" which may be even more urgent than seeing the other side of the Moon.

W. P. D. WIGHTMAN

Atlas of the Universe
By B. R. Ernst and T. J. De Vries (*Nelson, 226 pp., 42s.*)
This lavishly illustrated encyclopedia of the universe and the methods of astronomy must be among the most comprehensive and informative introductions to the subject yet published. It opens with 103 pages of plates and captions showing nearly all the important objects to be seen in the sky together with an excellent series of diagrams summarising such topics as solar radiation, stellar spectroscopy and the evolution of the solar system, stars, galaxies and the universe as a whole. The last half of the book is set out as an encyclopedia and contains, besides the text, about 200 explanatory diagrams. On the whole this section is admirable, but there are one or two oddities. Why, for example, do the steady state theories rate only 11 lines—a small fraction of the space devoted to evolutionary theories of the universe?

Medicine and the Navy
By Christopher Lloyd and J. L. S. Coulter (*T. E. Livingstone Ltd., 401 pp., 50s.*).
The authors are to be congratulated in producing a compulsively readable volume. An immense amount of research work, as indicated by the references quoted, must have been done to establish the authenticity of the relevant facts and then to blend them into a masterpiece of English historical literature.

This volume could have been a dull account of the sequence of events in the progress of naval medicine; but with skilful use of the historical facts and with a high style of story telling it should appeal to a very wide public.

SCIENCE SURVEY TWO

Edited by A. W. HASLETT and JOHN ST. JOHN

Foreword by SIR WILFRED LE GROS CLARK, F.R.S.

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The second issue of this annual survey of recent advances and developments in the scientific field maintains the standard of the first volume, described in The New Scientist as "a fine spectrogram of science" and by The Sunday Times as covering "practically every subject which has made scientific news in the past few years."

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Cybernetics (2nd edition)
By Norbert Weiner (*M.I.T. Press & John Wiley, New York, 212 pp., 52s.*)

When Norbert Weiner wrote the first edition of this great book some thirteen years ago he launched a revolution. Few people who have read it would deny that it is among the most influential and germinal documents of this century; certainly it has come to be one of the most widely discussed books in scientific history. Dealing with the then new science of cybernetics—the study of control and communication in animals and machines—it touched on practically every branch of science and brought a new, vigorous life to such apparently unrelated disciplines as physiology, psychology, mathematics and engineering. But the effects were not confined to science—Weiner's thinking about man and machines probed deep to the roots of human society itself, and thus was fundamental to economics, politics and even business.

Since the first edition times have changed. As Weiner states in the introduction to this new edition, the role of feedback in engineering and biological systems, and the cybernetic approach generally, have now become well established. The automata which the first edition barely forecast have come into their own, and the related social dangers against which he warned (also in the smaller popular companion, "The Human Use of Human Beings") have risen well above the horizon. And so he has moved on and largely re-written the book to include the new developments and ideas of the last ten years. He has also included two extra chapters, one giving a very general account of learning and self-reproducing machines, and the other a mathematical description of some aspects of "brain waves and self-organising systems." As with the first edition, laymen should be warned that amongst the brilliant, lucid writing of most of the book there are several sections which demand quite an advanced understanding of mathematics.

Encyclopedia of the Biological Sciences
by Peter Gray *(Chapman & Hall, 1,119 pp., 160s.)*

This 1,000 pages volume of information written by experts "selected for their international reputation" is aimed at both professional biologists and laymen. It is unlikely that the former will find it as useful as its price demands and difficult to see why the latter should need such a specialist production, but the 800 articles are written for the most part with a clarity that deserves a better standard of illustration. It is a pity that there are so few cross references.

Reason and Morals
By John Wilson *(Cambridge University Press, 185 pp., 15s.)*

This little book is an admirable sequel to the author's first and highly successful "Language and the Pursuit of Truth." In it Mr Wilson turns to the problem of morality in an age that is now well served in this area by its philosophers. To most of them questions of morality break down into discussions of individual cases which must be examined on their own merit. And among the positivist philosophers one can find fewer and fewer who are willing to discuss a rational basis for morality. This book is a very happy step in the right direction.

The text is well argued and extremely well written for this sort of thing. His style, however, brings up one point which might be mentioned here. To what extent can ordinary language be used in discussing complex ideas? The psychologist would be on his guard here because language is stretched to the breaking point. In the space of a page, a word may be used in three or four senses that may not be equated. In Gertrude Stein this was carried to high art, and ambiguity, William Empson is forever telling us, is not despicable. But does it belong in scientific or philosophical work?

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LETTER TO THE EDITOR

The Two Cultures

Sir:

The article "A Bridge from Arts to Science" by A. D. Peterson (DISCOVERY, September 1961), is very timely in emphasising the need for *all* well-educated people to have "a map of (scientific) knowledge." But Mr. Peterson's claim that "for the advancement of knowledge or the solution of problems, the fully trained mind will usually be better for having trained in the methods of both the Sciences and the Arts" must surely be challenged.

As regards the solution of problems (presumably the practical ones confronting Mankind), it has been appreciated for some time by UNESCO that the best way to assist the under-developed countries is through the direct help of visiting scientists who study the problems at first hand. Even in technologically advanced countries like the United Kingdom the scientific method is being employed more and more to the solution of problems in industry. I cannot foresee that people are going to continue using manual work, however skilled, in producing the materials of our welfare if machines can be constructed to do the work more efficiently; and in view of the recent developments in electronics the machines may well out-perform men in time to come. Thus it does not appear that the method of "sympathetic insight" is necessary in the solution of practical problems either.

One can only justifiably conclude from present trends in education in both the U.S.A. and the U.S.S.R. that the scientists and engineers will, in a few decades time, outnumber those trained in all other disciplines by a considerable figure; once this situation comes about, there will be a strong force for the formation of a world government based on scientific knowledge and not on the short-sighted views of present-day national government.

S. ARCHER

Physics Department, Rhodes University, Grahamstown, South Africa

THE AUTHORS

DR LEWIS WOLPERT (*The Forces that Shape the Embryo*) is a lecturer in zoology at King's College, London. Originally trained as an engineer, he has worked on cell cleavage and is now studying cell movements and the cellular basis of morphogenesis.

DR TRYGGVE GUSTAFSON is head of the Department of Developmental Physiology at the Wenner-Gren Institute, Stockholm. His current interest is in development biology.

DR LAWRENCE C. PAYNE (*Remaining Barriers to Automation*) is a leading authority on automation who is currently directing a programme to explore the scope for industrial and medical automation. After working with Dirac on particle physics and on statistical problems of genetics, he was concerned for a time with the automation of air defence and civil aviation traffic control.

H. S. WOLFF (*Measuring Human Stress*) works in the Division of Human Physiology at the National Institute for Medical Research where he was responsible for starting the bioengineering laboratory.

ALBERT GHIORSO (*The Search for New Elements*) has been co-discoverer of elements 95-103 inclusive and directed the work on the discovery of elements 99 to 103. Director of the heavy ion linear accelerator at the Lawrence Radiation Laboratory, Berkeley, his main past research has been concerned with the systematics of alpha radioactivity and the isolation of new isotopes.

J. A. C. BROWN (*In Defence of Freud*) is at present working on a study of propaganda while practising as a private psychiatrist. His past researches have been on the origin and treatment of battle neurosis and group psychology in industry.

DR R. L. HOLMES (*Environmental Control of Reproduction*) is a senior lecturer in anatomy at the Medical School, Birmingham University. Before his current research on the hypothalamus and the pituitary gland, he studied the central and peripheral nervous system.

ADVERTISER'S ANNOUNCEMENT

The Amazing Potentialities of Memory

I LITTLE thought when I arrived at my friend Borg's house that I was about to see something truly extraordinary, and to increase my mental powers ten-fold.

He had asked me to come to Stockholm to lecture to the Swedes about Lister and other British scientists. On the evening of my arrival, after the champagne, our conversation turned naturally to the problems of public speaking and to the great labour imposed on us lecturers by the need to be word perfect in our lectures.

Borg then told me that his power of memory would probably amaze me—and I had known him, while we were studying law together in Paris, to have the most deplorable memory!

So he went to the end of the dining room and asked me to write down a hundred three-figure numbers, calling each one out in a clear voice. When I had filled the edge of an old newspaper with figures, *Borg repeated them to me in the order in which I had written them down and then in reverse order, that is beginning with the last number. He also allowed me to ask him the relative position of different numbers: for example, which was the 24th, the 72nd, and the 38th, and I noticed that he replied to all my questions at once and without effort, as if the figures which I had written on the paper had been also written in his brain.*

I was dumbfounded by such a feat and sought in vain for the trick which enabled him to achieve it. My friend then said: "The thing you have just seen and which seems so remarkable is, in fact, quite simple; everybody has a memory good enough to do the same, but few indeed can use this wonderful faculty."

He then revealed to me how I could achieve a similar feat of memory, and I at once mastered the secret—without mistakes and without effort—as you too will master it tomorrow.

But I did not stop at these amusing experiments. I applied the principles I had learned in my daily work. I could now remember, with unbelievable facility, the lectures I heard and those which I gave myself, the names of people I met—even if it was only once—as well as their addresses, and a thousand other details which were most useful to me. *Finally, I discovered after a while that not only had my memory improved, but that I had also acquired greater powers of concentration; a surer judgment—which is by no means surprising since the keenness of our intellect is primarily dependent on the number and variety of the things we remember.*

If you would like to share this experience and to possess those mental powers which are still our best chance of success in life, ask C. R. Borg to send you his interesting booklet *The Eternal Laws of Success*—he will send it free to anyone who wants to improve his memory. Here is the address: *C. R. Borg, c/o Aubanel Publishers, 14 Highfield Road, Rathgar, Dublin 6, Ireland.*

Write now—while copies of this booklet are still available. L. CONWAY.

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FORTHCOMING MEETINGS

November 10, 1961: Photography from Rockets and Satellites. R. Hall.

November 22, 1961: One-day Symposium on "Materials in Space Technology." 9.30 a.m.-5.30 p.m.

December 2, 1961: International Law Extra-terrestrially applied. Dr. Bin Cheng.

January 5, 1962: Life in the Universe. Prof. O. Lowenstein.

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The National Physical Laboratory (D.S.I.R.), Teddington, Middlesex, requires Scientific/Senior Scientific Officers for work in Light Division on the following:—

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2. Physicist to carry out research in the application of optics to problems of fine measurement. Ref. 54 Y.
3. Physicist with background in physical optics or interferometry to study stimulated emission from ruby and other 'optical maser' materials. Ref. 53 Y.

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surface activity

For all practical purposes surface activity began with Adam—or so, for convenience, the detergent chemist thinks. He does not mean the biblical Adam, of course, although there is an implied analogy which, conceding important happenings prior to Adam's appearance on the scene, nevertheless considers him to have directed matters on to a systematic course, and to have made it clear that not only could knowledge of the subject lead to understanding, but understanding to greater knowledge. Surface activity, in a sense, is not a property of surfaces but an effect induced therein by unbalanced molecular forces, and our knowledge and understanding of surface phenomena are derived from the pioneer work of Willard Gibbs, Langmuir, Rideal, McBain, Hartley Harkins and of Adam himself. Not that the subject is yet exhausted The four volumes of the Proceedings of the Second International Congress on Surface Activity, to which Unilever scientists contributed, bear witness to the scope and diversity of its present applications—to flotation, adhesion, emulsion, lubrication and detergency—and to further problems that still await solution.

Not unnaturally, Unilever has an almost generic interest in surface activity, as their products—soaps, fatty acids and fatty alcohols—have been classic materials for study. We move with the times, and Durham, Jones, McDonnell and their co-workers are investigating an ever-widening variety of surface active agents to elucidate their patterns of behaviour.

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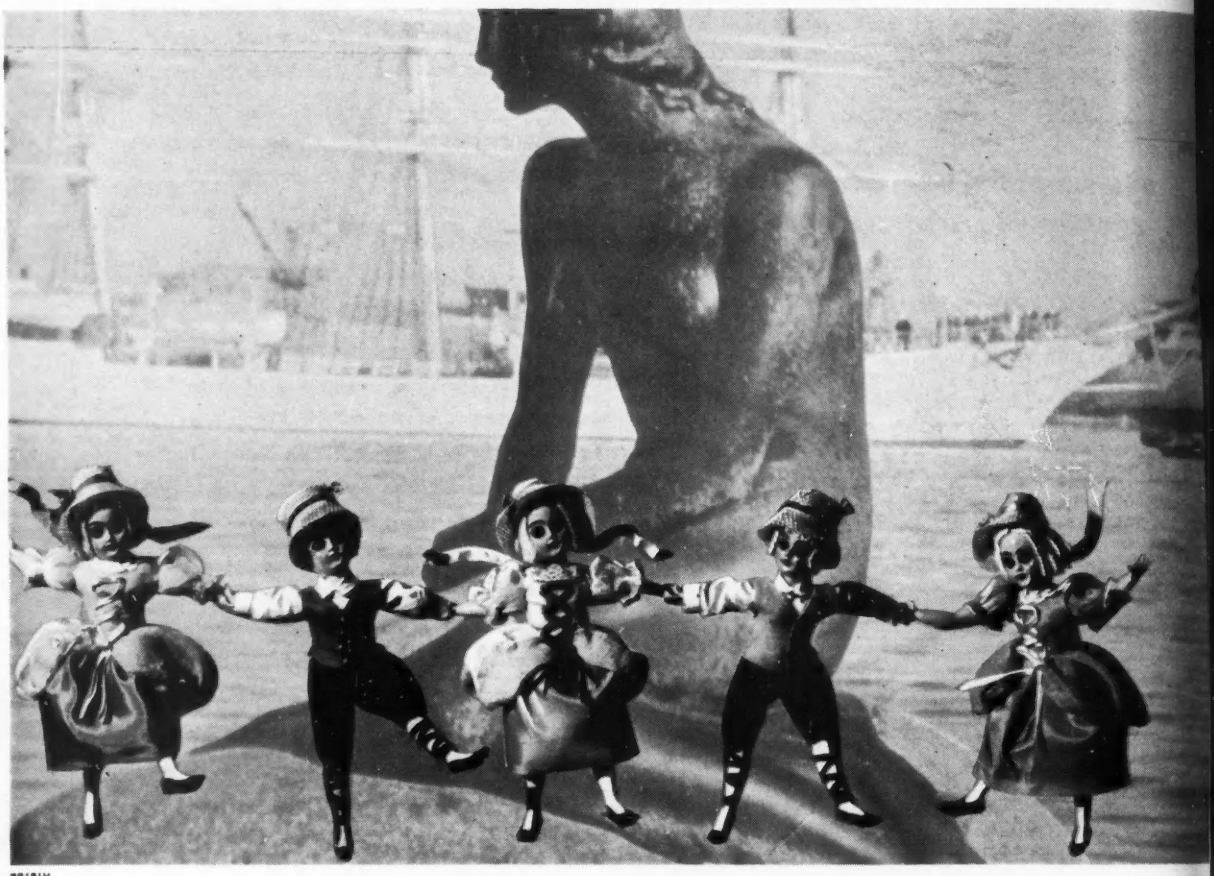
Danish molecules dance an English jig



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New landmarks are appearing on Copenhagen's waterfront. Soon after Christmas a valve will be opened in a pipeline from the Maersk refinery, which supplies the city with most of its gas, and a stream of ethylene will begin the intricate journey through compressors and reaction vessels that will transform it into one of the world's most versatile plastics: polythene.

The high-pressure process that persuades the invisible molecules of an invisible gas to choose partners, link up in long chains and form a tough, resilient plastic, was discovered by I.C.I., Britain's leading chemical company; and today it is used to make most of the one million tons of polythene produced every year throughout the world. In Britain, Australia, Canada and India, I.C.I. and its subsidiary companies operate plants making 'Alkathene' polythene for everything from squeeze-bottles and nailbrushes to packaging film and cable insulation. In seven other countries, 14 manufacturers are licensed by I.C.I. to make polythene, and to build the new polythene plant in Copenhagen, I.C.I. has joined forces with the A. P. Møller Shipping Companies. Once again, I.C.I.'s mastery of mammoth pressures and capricious temperatures will make the molecules dance.

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